GUIDEBOOK NO. 15

# SEDIMENTOLOGY AND PROVENANCE OF CARBONIFEROUS AND PERMIAN ROCKS OF ATHENS COUNTY, SOUTHEASTERN OHIO

by

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Originally prepared for the 1998 North-Central Section meeting
of the Geological Society of America

Columbus
1998

DIVISION OF GEOLOGICAL SURVEY

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This guidebook was prepared for an authors-led field trip in conjunction with the 1998 North-Central Section meeting of the Geological Society of America. Subsequent users of this guidebook must take appropriate caution when visiting any of the sites. This guidebook has been edited by the Ohio Division of Geological Survey, but has not been reviewed for scientific content. The views and interpretations expressed are those of the authors. The Division of Geological Survey disclaims any responsibility for interpretations and conclusions.

Cover illustration: Stacked sandstone bodies in the lower portion of the Connellsville sandstone (Pennsylvanian, Conemaugh Group) on the east side of Peach Ridge along U.S. Rte. 33 in Athens County, Ohio (see Stop 2 discussion). Remnants of floodplain mudstones are preserved within the section.

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FIGURES

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## INTRODUCTION

The focus of this trip is exposures of Pennsylvanian-age sediments in southeastern Ohio. The increased understanding of the global and regional forces acting during the Pennsylvanian has continued to fuel the debate regarding the relative influence of tectonic, eustatic, and climatic controls on the development of the Pennsylvanian cyclothems. Most of the recent studies have concentrated either in the midcontinent (for example, Heckel, 1984, 1994; Klein, 1994) or in more proximal foreland-basin settings (Cecil and others, 1985; Donaldson and others, 1985; Belt and Lyons, 1989; Cecil, 1990). The sediments in southeastern Ohio, by contrast, were deposited in a relatively unstudied setting, the distal foreland basin, where the tectonic influence on sedimentation should have been minimal. This area is, therefore, a logical setting to examine the relative impact of eustasy and climate on sedimentation patterns.

## GEOLOGIC SETTING

### REGIONAL SETTING

Early studies of the Appalachian coal basins clearly recognized the distinctive nature of upper Carboniferous sediments in eastern North America. The heterolithic nature of the rocks prevented conventional mapping procedures from being applied and, instead, the section was divided into productive and barren units based on coal development. It is worth noting that the "barren" measures of the early workers actually contain numerous coal seams (Ashley, 1907). These seams are thinner and less extensive than those in the "productive" measures and were thus uneconomic for the conditions at the time. Contacts between units were logically placed at the base of major coal seams. These divisions later became formally named groups and have been extended from Pennsylvania and West Virginia into southeastern Ohio (fig. 1).

The overall setting has been well described in numerous papers (Cecil and others, 1985; Donaldson and others, 1985) and only a brief overview is presented here. The Pennsylvanian of southeastern Ohio was deposited in the distal reaches of the Appalachian foreland basin (fig. 1) during the Alleghanian phase of mountain building. The paleogeographic position of the region ranged between 5° and 15° south of the paleoequator; overall drift was northward throughout the Carboniferous and Permian (Opdyke and DiVenere, 1994; Scotese, 1994) (fig. 2). The varied sediments typical of the Pennsylvanian were deposited in part owing to the eustatic control imposed by the southern Gondwanan glaciations that occurred throughout this time interval. Regional compilations show that in addition to medium- and short-term sea-level fluctuations, there was an overall increase in sea level throughout the Early to Middle Pennsylvanian and a decrease in the Late Pennsylvanian (Ross and Ross, 1987) (fig. 2).

The type of climate and its role in the control of facies patterns within Pennsylvanian sediments also are the subject of a vigorous and ongoing debate. Much of the interpretation has come from coal-bed studies (Cecil and others, 1985; Schutter and Heckel, 1985; Cecil, 1990; DiMichele and others, 1996). However, aside from variations in interpretations in these studies, coals form only a small portion of the lithostratigraphic record. More common within the section, but less well studied, are paleosols and lacustrine/brackish carbonates (Weedman, 1994; Joeckel, 1995). Studies of both paleosols and nonmarine carbonates from specific localities suggest the presence of a seasonal climate, but too little is known of the changes throughout the entire section to determine if there was a systematic (or variable) climate change that produced recognizable changes in the soils and lacustrine/brackish carbonates.

### LOCAL SETTING

The distal-foreland-basin setting of the Pennsylvanian in southeastern Ohio is evident from the shallow (0.3°) eastward dips (Sturgeon and associates, 1958) and the overall decrease in thickness of the section (fig. 1). The 450 meters of section present from the base of the Pottsville Group to the top of the Monongahela Group represents an order of magnitude decrease in the preserved thickness of sediment compared to the equivalent strata in more proximal foreland settings. The driving force for the early geologic investigations were the coal and iron resources present (Condit, 1912). Broad correlations were made with sections in adjacent states on the basis of key marker beds, such as the Ames limestone. The thin and in places discontinuous nature of the marine limestones resulted in numerous variations in correlation that are still the subject of modification (Slucher and Rice, 1994; Joeckel, 1995).

The most comprehensive study of the Pennsylvanian and Permian sedimentary rocks in southeastern Ohio is that of Sturgeon and associates (1958). The main driving force in this study was the cyclothem paradigm of Wanless and Weller (1932). Sturgeon and associates (1958) clearly understood the limitations inherent in using this paradigm to describe the sediments and noted that no complete cyclothem was present in Athens County and that entire cyclothems may be absent. Nevertheless, the 450 meters of sedimentary rocks from the upper Pottsville through the basal Dunkard were described and divided into 45 named cyclothems on the basis of the descriptions of work done elsewhere in Ohio and in adjacent states.

This field trip will illustrate the variations in depositional style, sediment composition, and provenance within the Pennsylvanian rocks exposed in a transect across Athens County (fig. 3). Specifically, we wish to examine (1) the im-

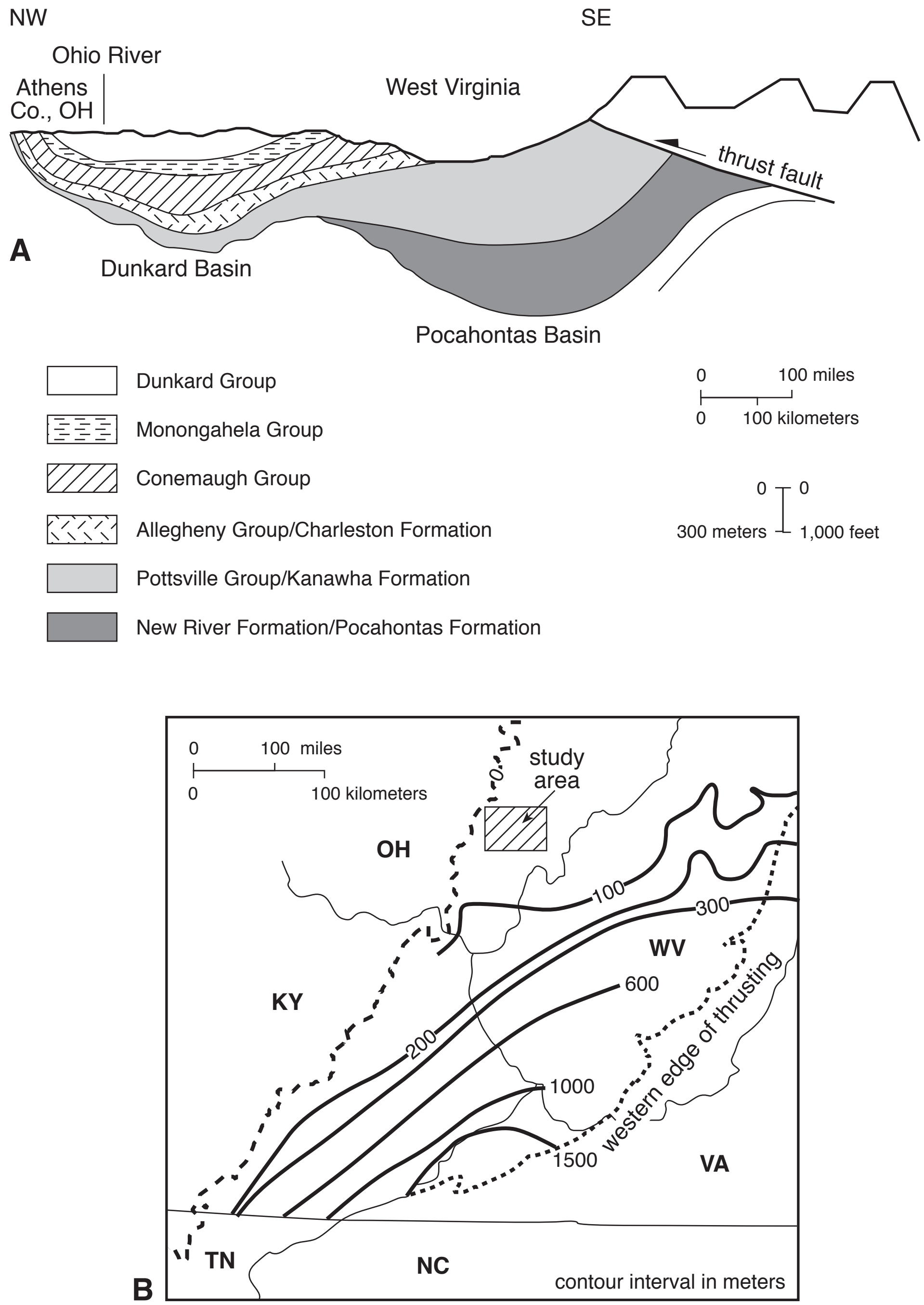



FIGURE 1.—**A**, Regional cross section showing the correlation of strata from West Virginia and Pennsylvania into Ohio (after Donaldson and others, 1985). **B**, Generalized isopach map of the Pottsville Group showing the northeastward thinning of the unit from proximal to distal foreland basin (after Presley and Donaldson, 1984).

plications of applying the sequence stratigraphic paradigm to these sedimentary rocks, (2) the climate implications of the paleosols and the presence of nonmarine carbonates within the section, and (3) the tectonic controls on sediment accumulation from provenance data from the sandstones within the section.

## SEQUENCE STRATIGRAPHY

### GENERAL MODEL

Sequence stratigraphy, which emphasizes relative sea-level change, was initially applied to passive-margin settings (Van Wagoner and others, 1990). The change in tectonic setting to a foreland basin has important implications for the spatial distribution and preservation potential of the various systems tracts. In general, the location of the locus of maximum rate of formation of accommodation space directly adjacent to the sediment source in foreland basins means that the nonmarine record has a much better chance of preservation and the major unconformities occur in more distal rather than proximal basin settings in comparison to a passive margin. The distal foreland margin in particular, whether or not a forebulge is generated or identified, is a region that is sensitive to small changes in relative sea level.

The low depositional slope of the distal foreland setting produces abrupt shifts in facies and systems tracts during changes in relative sea level. Minor sea-level variations may well result in deposition of sediments that are either removed or extensively modified through pedogenesis in subsequent fluctuations. A generalized model for sediment deposition in a foreland-basin setting may be summarized as a transgressive systems tract (TST) composed of coals or shales that culminate in the deposition of a limestone as the zone of maximum flooding is reached. The subsequent drop in relative sea level results in the influx of mudstones and channel sandstones that are capped in most areas by an exposure surface represented by a paleosol.

## CYCLOTHEMS OR SEQUENCES?

Does the application of sequence stratigraphy make any difference to the geologic interpretations of the Pennsylvanian sediments in southeastern Ohio? The repetitive nature of the Pennsylvanian sediments in North America was first interpreted by Udden (1912) from exposures in the Illinois Basin as a response to fluctuations in relative sea level—at the time considered a response to epeirogenic movements. Udden (1912) defined the cycles as starting with a transgression and culminating in a regression and exposure that led to the development of a fire clay. Weller (1930) modified Udden's definition by placing the base of a cycle, later termed cyclothem by Wanless and Weller (1932), at the base of the major sandstone. These sandstones, unfortunately, are commonly discontinuous. Subsequent studies (for example, Heckel, 1984, 1994; Chesnut, 1994) showed that the expression of the cyclothems within various basins changed in response to local variations in sedimentation and subsidence rates. The alternations present in the proximal Appalachian foreland basin setting can scarcely be termed cyclothems in view of the fact they lack virtually every important component, including the marine limestones and mudstones.

The application of sequence stratigraphy to these Appalachian sedimentary sequences requires a return to the original definition of a cycle (fig. 4). The bounding unconformities within the sequence-stratigraphic model are mappable entities that separate one group of strata from another in a temporal as well as a physical sense. The unconformities at the base of the sandstones, although they can erode deeply enough to intersect sequence boundaries, are commonly only local events and therefore not valid sequence stratigraphic boundaries. Instead, the original definition of Udden (1912) stands as the logical allostratigraphic subdivision of the strata.

The allostratigraphic subdivision of the cycles in principle allows correlation of the cycles even when components of an individual cycle are missing through either erosion or nondeposition. In practice, however, the erosion associated with sea-level fall throughout the distal-foreland-basin setting in southeastern Ohio means that key marker beds, such as those provided by the marine limestones, are necessary to confidently extend the sequences without continuous or very closely spaced outcrops. Within the Conemaugh Group such marker beds are relatively common. In the Monongahela Group, marine carbonates are absent and local marker beds of nonmarine/brackish carbonates must suffice.

## CLIMATE

The potential for climate to influence the formation of the Pennsylvanian cyclothems has been noted since at least Weller (1930). The attempts to find a means to resolve this problem have intensified in the past two decades with the advent of more paleomagnetic and paleosol data. The general setting of the Pennsylvanian, as determined from paleomagnetic studies (Opdyke and DiVenere, 1994), indicates a northward drift from approximately 7°-14°S to 1°-7°S latitude (fig. 2). The modern climate in this range of latitude varies from wet equatorial (0°-10°) to monsoon and trade-wind littoral (5°-25°) to wet-dry tropical (5°-20°). Only the most extreme southern position approaches the dry tropical climate (15°-25°) (Strahler and Strahler, 1989). There are at least two major problems in using the present as a direct key to the past in this instance. First, the presence of the Appalachian Mountains as a major east-west barrier in the Pennsylvanian at this paleolatitude has no modern analog. The orographic enhancement of precipitation patterns may be significant (Otto-Bleisner, 1993). Second, the presence of rapid global climate changes brought about by the southern glaciations during the Pennsylvanian probably affected the widths of the major circulation cells in the atmosphere (Perlmutter and Matthews, 1990, 1994). The modeled variations in the boundary of the Hadley circulation cell by Perlmutter and Matthews (1990) range from approximately 40° to 20° latitude. This fluctuation, which also is influenced by local factors such as orographic effects, could change local climates from wet equatorial to dry tropical, especially in the Early Pennsylvanian.

The geologic factors available to try to decipher the paleoclimate signal are paleosols, coals, lacustrine limestones, and sandstones. Each of the first three lithologies mainly occur in different sequence stratigraphic settings. The coals are most common in the transgressive systems tract, lacustrine limestones in the highstand systems tract, and paleosols cap the highstand deposits. The fluvial sandstones can occur throughout the interval but are most common in the upper highstand and lowstand systems tracts. If cyclothem development occurred during a fluctuating climate pattern as suggested by Perlmutter and Matthews (1990), it would not be surprising to find that each lithology pointed to a different climate, even within a single cyclothem! In the following sections we discuss the role of paleosols, limestones, and sandstone provenance in inferring the paleoclimate signal in Athens County.

## PALEOSOLS

The paleosols within Athens County are largely unstudied. The only detailed published study thus far (Joeckel, 1995) focused on a single stratigraphic interval (Ames limestone, Conemaugh Group). Joeckel concluded that the interval was largely composed of vertic paleosols suggesting a seasonal climate (that is, either trade-wind littoral or wet-dry tropical). Other studies elsewhere (Schutter and Heckel, 1985; Gill and Yemane, 1996) have interpreted profiles as vertic paleosols and Ultisols. Retallack (1992, 1994) made the case for the existence of numerous kinds of paleosols within the Pennsylvanian sediments. However, in addition to the large number of factors that contribute to soil formation, both biotic and physical, that make modern soils so complex (Buol and others, 1989), we have to add depositional and diagenetic overprints (Schutter and Heckel, 1985; Johnson and others, 1997).

Our preliminary work correlating sequences in the vicinity of Athens shows that paleosols occur throughout the section. They can be recognized, if not identified, by a vertical change in structure within the sediment. Mudstones deposited by

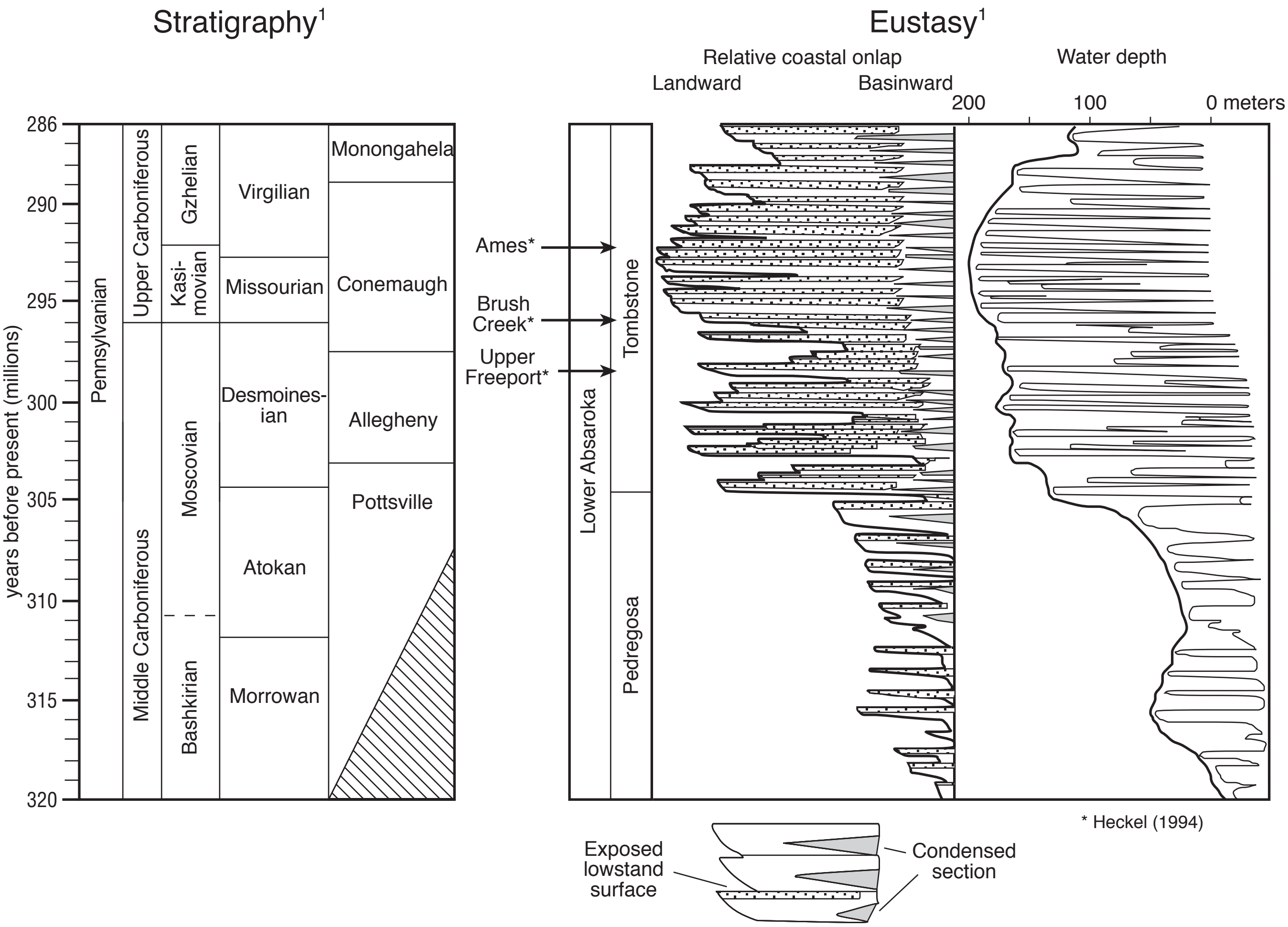



FIGURE 2.—Compilation of inferred eustatic, paleolatitudinal, and

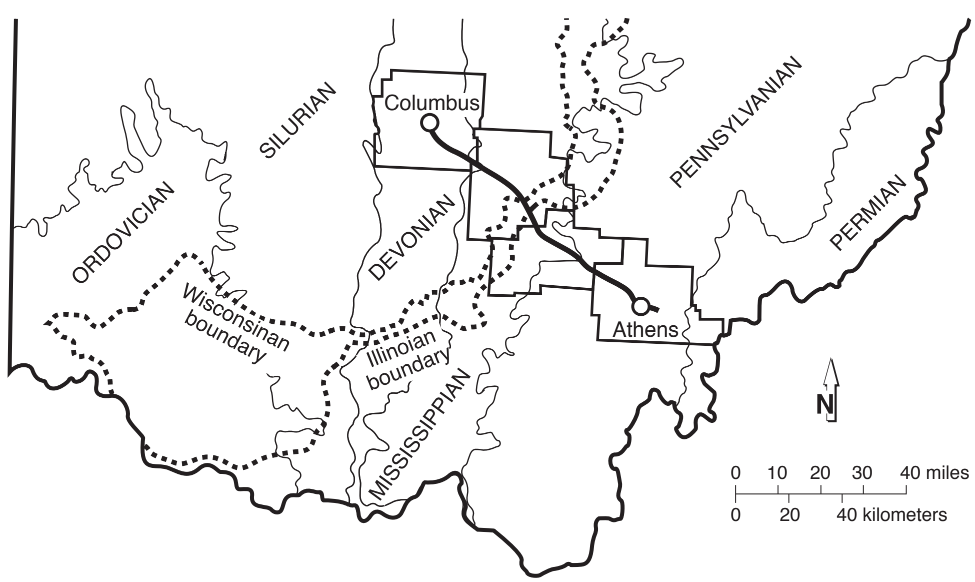
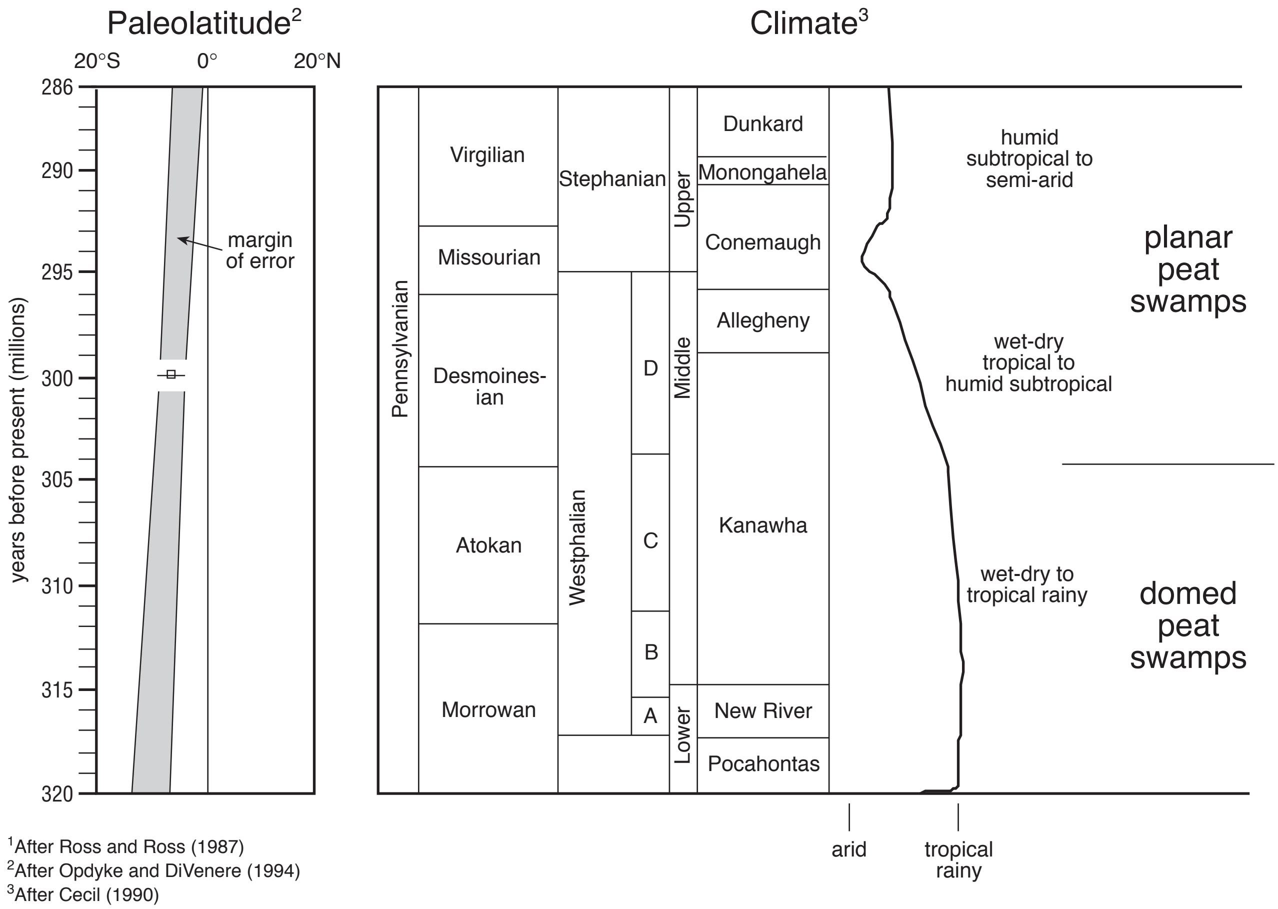



FIGURE 3.—Generalized map of field-trip route.




climatic variations during the Pennsylvanian of eastern North America.

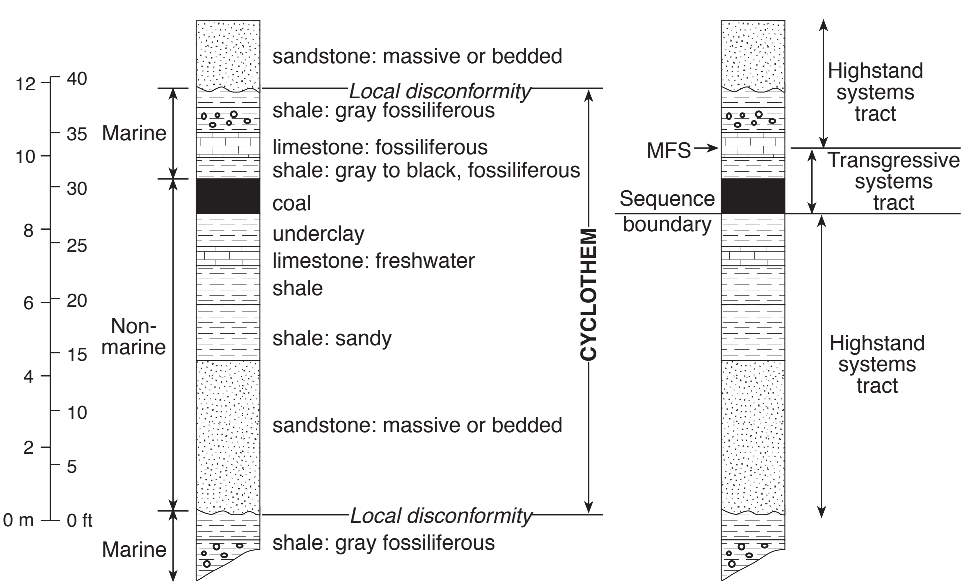



FIGURE 4.—Historical comparison of cycles, cyclothems, and sequences. Udden (1912) placed his cycle boundaries at the base of coals (top of paleosols), whereas Weller and Wanless (1932) placed their cyclothem boundaries at the base of sandstones. Sequence-stratigraphic and allostratigraphic boundaries (unconformities) are more consistent with the definition of Udden. **MFS** = maximum flooding surface.

water have laminations unless bioturbation has been excessive. The homogenization of the sediments and formation of a blocky fracture, especially within mudstones, is indicative of postdepositional modification—a paleosol. The changes within sandstones may be less pronounced but include destruction of sedimentary layering and structures as well as an increase in clay content without a decrease in sand grain size up section.

Characteristics of paleosols, such as color, structure, and thickness, change markedly below each sequence boundary even between closely spaced sections. This observation isn't very surprising because subtle changes in parent material, vegetation, elevation, etc., result in areally restricted polypedons (Buol and others, 1989). Color, thickness, and structure vary widely. To this point we have only identified the locations of soils in measured sections and feel it is premature to place labels on most of the units. Certainly the presence of paleosols greater than 3 meters thick that contain distinctive color and texture horizons argues for a complex history of formation, including burial of earlier soils and overprinting by subsequent pedogenesis.

## NONMARINE CARBONATES

Accumulation of carbonates in continental environments is heavily dependent on input source. Continental waters, unlike sea water, do not necessarily precipitate calcite when a siliciclastic input is absent. A large variation in the chemistry of fresh waters is the result of weathering and erosion of a large spectrum of rock types in any given source area or the result of lithology of the input aquifer. The appropriate ions must first be present for calcite to accumulate; possible concentrations range from undersaturated to supersaturated, again depending on the input source. Seven sedimentary origins for nonmarine carbonates are here recognized: (1) paleoconditions conducive to river transport and deposition/precipitation of clastic carbonates; (2) carbonate input through localized springs (ground-water flow above the regional water table); (3) ground-water discharge on a local or regional level, including seeps and hydrothermal vents; (4) carbonate accumulation through long-term pedogenic processes in an arid environment; (5) carbonate precipitation in undersaturated conditions due to biochemical conditions, as in saline environments and/or during seasonal changes in fresh water (varves); (6) carbonate cave deposits (chemical precipitation of calcite); and (7) eolian input (wind clastics).

In order to ascertain the origin of a nonmarine carbonate deposit, the source of carbonate input must first be determined (Jones and Bowser, 1978). The percentage of calcium-bearing source-area rocks (such as calcic igneous rocks and carbonates) must first be examined where possible; over-land transport through sediment load can produce layers of clastic carbonates (Tandon and Narayan, 1981; Gierlowski-Kordesch and others, 1991; Bellanca and others, 1992; Cavinato, 1993), even in siliciclastic-dominated conditions (see Smith, 1994; Talbot and others, 1994; Valero Garcés and others, 1994; Magee and others, 1995). In addition, an analysis of the sedimentology (and climate of deposition) of the rocks surrounding a carbonate deposit will aid in the determination of origin if carbonate accumulation is related to climatic factors, as in the development of a K-horizon (calcrete) in a soil under arid conditions (Wright and others, 1995), as well as ground-water calcrete/dolocrete (Arakel and McConchie, 1982; Leslie and others, 1992; Colson and Cojan, 1996) or seepage mounds (Hay and others, 1986; Calvo and others, 1995) as a result of local to regional ground-water discharge (dependent on tectonics as well as climate). Fine carbonate lamination (varves or varvelike layers) occurs in offshore lake sediments, both saline and fresh (Kelts and Hsü, 1978; Renaut, 1990; Last and De Deckker, 1992). Conditions for precipitation, even in slightly undersaturated waters, may be connected to seasonal extremes in temperature, pH, and salinity related to microbial activity (Kelts and Hsü, 1978; Dean, 1981; Thompson and others, 1990). Cave carbonates are associated with large-scale karstic features (Chafetz and Butler, 1980; Esteban and Klappa, 1983; Gonzalez and Lohmann, 1988; Cañaveras and others, 1996). Wind-blown grains also can contribute ions to a continental carbonate system (for example, Lattman, 1973; Talbot and others, 1994).

If a carbonate layer is localized and appears to be unrelated hydrodynamically to its surrounding sediments and there is no possible over-land carbonate source (for example, micrites associated with siliciclastic debris-flow conglomerates), it may be a spring deposit (Renaut and Tiercelin, 1994). Some hot to warm spring deposits are characterized by unique textures, such as spherulitic crystals, feather dendrites, and stellate clusters (for example, Chafetz and others, 1991; Jones and Renaut, 1995). Microbial bioherms and tufas in fresh to more saline waters of ancient and modern lakes, as well as in river beds (for example, Mouline, 1977; Cohen and Thouin, 1987; Ordoñez and Garcia del Cura, 1983; Thompson and others, 1990; Benson, 1994; Rouchy and others, 1996; Ford and Pedley, 1996) occur in calcium-rich waters interpreted as having a source from cold to warm springs as well as ground-water discharge. There are no distinguishable textures in some of these spring and ground-water deposits; they can be identical to clastic carbonate deposits. Both kinds of deposits can contain massive micrites, as well as microbial textures. Micrites can occur as precipitates from springs, ground-water discharge, or fluvial dissolved load, or as diagenetically altered clastic carbonates.

Nonmarine carbonates from large modern tectonic systems (for example, Cohen and Thouin, 1987; Soreghan and Cohen, 1996; Jones and Renaut, 1996), as well as large and small ancient tectonic basins, such as rift, strike-slip, and foreland basins (for example, Smoot, 1978; Roelofs and Kilham, 1983; Janaway and Parnell, 1989; Platt, 1989; Stapf, 1989; Leslie and others, 1992; Valero Garcés and Gisbert Aguilar, 1992; Fregenal-Martínez and Meléndez, 1993; Lindqvist, 1994; Talbot, 1994; Bellanca and others, 1995), have been described as offshore lacustrine to palustrine to beach (clastic) to platform bench to tufa (travertine) to bioherm (stromatolites) deposits. The origin of carbonate generally is assumed to be exclusively from ground-water discharge or springs, though over-land sediment load cannot be discounted where source areas contain Ca-rich rocks (Rosen, 1994; Calvo and others, 1996; Quade and others, 1997).

## CLASTIC CARBONATES

Clastic (from the Greek word klastos, to break) sediments are derived from the weathering of rocks. A clastic rock is "a consolidated sedimentary rock composed principally of broken fragments that are derived from pre-existing rocks or from the solid products formed during chemical weathering of such rocks, and that have been transported mechanically to their places of deposition" (Bates and

Jackson, 1987). Clastic sedimentary rocks, therefore, can be of two types: siliciclastics (conglomerates, sandstones, shales) and clastic carbonates (rudstones, grainstones, intramicrites). Micrites, whose ions were transported as dissolved and suspended load over land from a source area, can be considered clastic as a solid precipitation product from the weathering process.

Many ancient nonmarine carbonate deposits (mostly micrites) associated with siliciclastics in various tectonic settings having Ca-rich source areas normally are found in quiet distal paleoconditions (for example, Friend and Moody-Stuart, 1970; Freytet and Plaziat, 1982; Demicco and others, 1987; Platt and Wright, 1992; Nadon, 1994; Talbot and others, 1994; Valero Garcés and Gierlowski-Kordesch, 1994; Sanz and others, 1995; Drummond and others, 1996) associated with lakes, floodplains, wetlands, or distal portions of alluvial fans. This situation is hydrodynamically compatible with settle out and/or precipitation in distal environments, equivalent to clastic clay-dominated zones. The reduced amount of clay and accumulation of carbonate in these distal areas are not necessarily attributable to a cessation of "clastic input" due to a climatic change to "aridity," a locally starved supply of "clastic" sediment, or a creation of topographic highs in midbasin to segregate siliciclastic from carbonate deposition, as commonly interpreted in the literature (for example, Nickel, 1985; Cecil, 1990; Arríbas and others, 1996; Talbot and Allen, 1996). These distal carbonates, covering wide areas, normally contain distinctive sedimentary and diagenetic structures, as well as fossils, that identify the paleoclimatic conditions (humid or arid) under which sedimentation/precipitation occurred (Platt and Wright, 1992; Wright and Platt, 1995) and are compatible with the interpreted paleoconditions of the surrounding siliciclastics. Carbonate sedimentary structures and isotopic values generally do not support any climate change as the cause of the carbonate deposition per se (for example, Smith, 1994; Drummond and others, 1996; Quade and others, 1997; Valero Garcés and others, 1997). An over-land transport and subsequent deposition are a more likely origin for these carbonates. Alternately, ground-water discharge is a possible origin, but a tectonic framework is necessary to establish ground-water flow directions and probable water conduits such as fault and fracture zones (for example, Hay and others, 1986; Jacobson and others, 1994; Rosen, 1994; Calvo and others, 1995) or even midbasin topographic highs.

A decrease in "clastic supply" within a siliciclastic system commonly is listed as the main reason for nonmarine carbonate accumulation in a siliciclastic system (Nickel, 1985; Cecil, 1990; Alonso Zarza and others, 1992; Talbot and Allen, 1996; and many others). Unfortunately, this decrease would certainly also include a decrease in water supply to the same area, whether by surface inflow or ground-water discharge. Large carbonate lakes having sediments containing subaqueous textures cannot form without a substantial water supply. When changes in type of sediment in a nonmarine sequence occur, for example, from siliciclastics to carbonates, it is also possible that the type of clastic supply was changing, owing to shifts in the source area because of tectonics. Carbonates can reach a depositional area by surface water (over-land transport), just as siliciclastics can—as bedload, suspended load, or dissolved load from a source area containing older carbonates or calcic basement rocks (Smoot, 1978; Platt and Wright, 1991). Carbonate transport differs from siliciclastic transport in that carbonates are very reactive at surface pressure and temperature (Gierlowski-Kordesch and others, 1991). Carbonate clasts are more prone to dissolution over a large transport distance, resulting in mostly dissolved load reaching distal areas where precipitation can occur (Valero Garcés and others, 1997). Also, carbonate clastic textures can easily be erased by synsedimentary and early diagenetic processes, such as recrystallization, sparmicritization, brecciation, remobilization, dissolution, reprecipitation, and pedogenesis (for example, Lattman, 1973; Freytet and Plaziat, 1982; Arríbas, 1986; Gierlowski-Kordesch and others, 1991), masking the true origin of the carbonate deposit. In other words, cross-bedded grainstones and planar-bedded rudstones can be quickly altered to massive micrites.

The relative percentage of carbonate-clastic vs. siliciclastic input into a system, as well as the distance of transport (very large or relatively small tectonic basins), can determine the facies distribution of clastic carbonates. In smaller basins, proximal carbonate bedload deposits as well as distal areas of accumulation/precipitation of carbonate indicate circumstances where carbonate load overwhelms minor siliciclastic influx. A large portion of a depositional system, from fluvial to lacustrine conditions, can be composed of carbonates, especially in small basins that have source areas dominated by carbonates. Carbonate bedload deposits (such as trough cross-bedded grainstones) can be preserved, exhibiting the clastic textures as proof for carbonate over-land input into the depositional system (Friend and Moody-Stuart, 1970; Nickel, 1982, 1985; Gierlowski-Kordesch and others, 1991; Cavinato, 1993; Fregenal-Martínez and Meléndez, 1993). In larger tectonic basins that have a mixed carbonate/siliciclastic source, mostly distal carbonate deposits are preserved; the carbonate is present in the sediment load but can only accumulate as lime deposits where it can be more or less separated from the siliciclastic load. Clastic textures also can form where early cemented carbonate (Branner, 1911; Dravis, 1996) in rivers and lakes can be broken, remobilized, and transported yet farther downstream. Interchannel wetland areas associated with siliciclastic-dominated anastomosed rivers, both modern and ancient, can contain carbonate lakes that are protected by levees and receive mostly suspended and dissolved loads (for example, Friend and Moody-Stuart, 1970; Aqrawi and Evans, 1994; Valero Garcés and Gierlowski-Kordesch, 1994; Weedman, 1994).

A solely spring or ground-water origin for many of these carbonates is hard to reconcile when the deposits are tens to hundreds of kilometers in extent and up to tens of meters thick. Contributions from ground water are always possible and have not yet been quantified in many lake systems (Rosen, 1994). A depositional area based on a limestone aquifer or very specific subsurface conditions associated with tectonically active basins within regional discharge areas could supply large amounts of appropriate ions into a system via ground water (see Smoot, 1983; Hay and others, 1986), but not necessarily over the entire extent of a basin. Surface drainage cannot be simply ignored as an input source, especially if Ca-rich rocks are present in the source area and clastic transport is possible, especially if there is evidence such as basin-edge conglomerates containing limestone clasts (for example, Szulc and Cwizewicz, 1989).

Within largely siliciclastic systems, criteria to differentiate between spring/ground-water and clastic carbonates, which can have similar textures, such as massive and/or microbial micrites, may be linked to (1) whether the deposit lies in a hydrodynamically incompatible position, that is, not a distal location, and (2) the lateral extent and shape of the carbonate layer, that is, is the deposit localized or restricted to tectonic lineaments or does it cover a large portion of the basin. Spring deposits are generally very limited in areal extent (for example, Renaut and Tiercelin, 1994; Quade and others, 1995). Existence of fossils indicating a surface ecosystem can be characteristic of both kinds of carbonates and should be identified to eliminate the possibility of soil or ground-water calcrete origin (Platt, 1992). Subsurface hydrology of the basin, tectonic origin of the basin, and source rocks surrounding the basin are all important in determining input sources of carbonate, although these data commonly are difficult to obtain for ancient basins, especially the amount of ground-water contribution. Of course, the sedimentologic packaging of the carbonates within the siliciclastic depositional system, such as position within fining-upward sequences or cycles as well as lateral relationships with associated siliciclastics, evaporites, or coal, and the sedimentary structures and fossils in the carbonates also aid in determining whether the carbonate accumulated as a result of hydrodynamic transport or spring/ground-water input. Stable-isotopic analyses may help separate clastic (detrital), primary, and diagenetic carbonates, as well as determine ground-water or rainfall influences (for example, Kelts and Talbot, 1990; Leslie and others, 1992; Platt, 1992; Andrews and others, 1993, 1997; Valero Garcés and others, 1997).

## PROVENANCE

Foreland basins have been extensively studied because they chronicle in great detail the tectonic and denudation history of the bounding mountain belt (Jordan, 1981). Provenance investigations commonly involve the use of ternary diagrams and classification schemes such as those of Dickinson (1985) to ascertain possible detrital sources for sandstones. Factors such as climate, relief, source terrane, and transport distance, which influence modal sand compositions, may be well defined but lack interpretive significance in the absence of a thorough understanding of their interplay at a particular instant. Another factor, which is seldom considered in provenance investigations, is the amount of information lost via diagenetic modification. Gold (1987), Saigal and others (1988), and Ramseyer and others (1992) all noted that diagenetic reactions which affect feldspar populations (dissolution and replacement) were extremely dependent on cement composition. Gold (1987) noted that the unaltered feldspar fraction of Miocene Gulf Coast sandstones in carbonate-cemented regions was 60 percent plagioclase and 40 percent K-feldspar. This composition was in marked contrast to regions that had different cements, where up to 75 percent of the plagioclase grains showed alteration (dissolution and/or replacement).

Detrital modes of Upper Carboniferous sandstones from the Appalachian foreland basin show a similar dependence on cement composition (fig. 5). However, there have been few systematic examinations of their provenance and heterogeneity. Several authors (Davis and Ehrlich, 1974; Cox and others, 1984; Greenlee, 1986; and Robinson and Prave, 1995) have gathered data on the provenance of Upper Carboniferous sandstones from the Appalachian foreland, but these authors considered the provenance of either individual sandstones or isolated samples. In addition, the aforementioned studies employed traditional methods of provenance discrimination, that is, conglomeratic clast orientation/composition or ternary plot analysis. The exceptions are the work of Davis and Ehrlich (1974) and Cox and others (1984) in the Pocahontas Basin of West Virginia. These authors used the presence of perthitic K-feldspar, microcline, and schistose fragments in Pottsville and Allegheny Group sandstones to document the degree of uplift and erosion of a granodioritic batholith and its halo of low- to medium-grade metamorphic rocks (fig. 6).

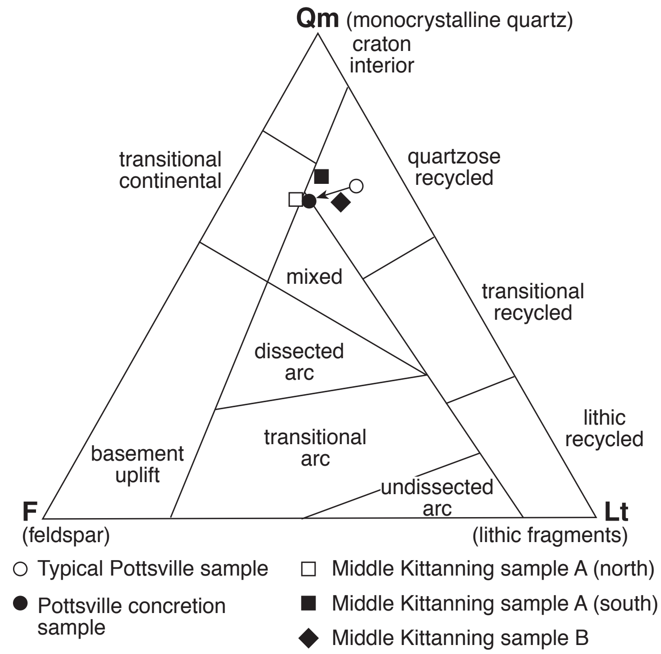



FIGURE 5.—Variations of interpreted source terrane from thin sections containing different cements (after Dickinson, 1985). Note the difference between the Pottsville carbonate concretion and the typically cemented Pottsville samples. The Middle Kittanning samples A and B are separated by only 0.05 meter. The two analyses for sample A were made within a concretion (north) and directly outside a concretion (south).

## ATHENS COUNTY SANDSTONE DATA

To expand the Upper Carboniferous provenance data within the northern Appalachian foreland, we analyzed 40 samples from 25 discrete sandstones that crop out in Athens County, Ohio. Samples span the upper Pottsville through

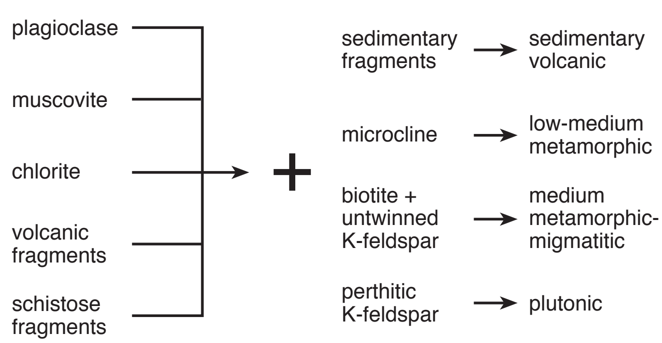



FIGURE 6.—Derivation of sandstone provenance types from measured thin-section parameters (after Davis and Ehrlich, 1974).

the lower Dunkard (Permian) Groups. Using modified criteria established by Davis and Ehrlich (1974), Basu and others (1975), and Mack and Jerzykiewicz (1989) (fig. 7), we took a somewhat new approach to provenance analysis in which grains are classified on the basis of genesis and tallied through the vertical section (fig. 8). In addition, we account for the presence of any diagenetic filters by examining samples from dissimilarly cemented regions of the same outcrop (fig. 5). This exercise was undertaken to illustrate the sensitivity of more commonly used methods of provenance data analysis.

| **Provenance** | **Criteria** |
|---|---|
| Sedimentary | Quartz grains with abraded overgrowths<br>Chert<br>Sedimentary rock fragments |
| Metamorphic | Plagioclase<br>Strained (>5° undulosity) monocrystalline quartz<br>Polycrystalline quartz<br>Metamorphic rock fragments |
| Plutonic | K-feldspar<br>Unstrained (<5° undulosity) monocrystalline quartz<br>Plutonic rock fragments |

FIGURE 7.—Summary of criteria used to establish provenance categories. Criteria modified from Davis and Erlich (1974), Basu and others (1975), and Mack and Jerzykiewicz (1989).

Figure 8 shows the variation in sandstone provenance through the Pennsylvanian to the basal Permian in Athens County. The vertical trends in sandstone composition indicate the three different types of provenance illustrated in figure 8. The sandstones are derived primarily from three main sources, plutonic (0-50 meters), mixed metamorphic-plutonic (50-153 meters), and metamorphic (153-372 meters). The metamorphic portion is punctuated twice by short-lived influxes of plutonic material (217 and 290 meters). The typical Pottsville sample in figure 5 is dominated by plutonic source-rock contributions, indicated by perthitic K-feldspar and unstrained monocrystalline quartz (fig. 9). The dominance of plutonic sources continued through middle Allegheny time.

The second vertical trend in composition begins in the Allegheny Group, in the Lower Freeport sandstone (61 meters), and ends below the Ames limestone (164 meters), the major formation boundary in the Conemaugh. The Ames limestone is used, in some regions, to divide the Conemaugh into the lower, marine Glenshaw Formation and upper, nonmarine Casselman Formation (Merrill, 1993). Samples of Ames age and older show a dramatically different signature than do those that are younger. Conemaugh samples that are pre-Ames (Glenshaw), as well as the Lower Freeport sample, show that plutonic sources are still a major contributor, although reduced relative to lower Allegheny and Pottsville Group samples. Metamorphic constituents climb from their subordinate contribution in Pottsville and lower Allegheny sandstones to become subequal with the plutonic constituents in lower, pre-Ames, Conemaugh sandstones.

The third vertical trend in composition is first manifested in the Ames sandstone (164 meters) and is indicated by systematic variations in the amount of metamorphic detritus relative to plutonic content. This variation consists of large, overwhelming, metamorphic contributions, which are punctuated by abrupt increases in plutonic contributions coupled with a declining metamorphic component. These fluctuations continue into the basal Permian, the limit of the study area.

As previously stated, diagenetic attenuation of provenance data also was examined, as well as its effect on provenance interpretation within the confines of a particular classification scheme (for example, Dickinson, 1985). The sample labeled Pottsville concretion in figure 5 is derived from a carbonate matrix section of an upper Pottsville sandstone. The sample labeled typical Pottsville is derived from a carbonate-poor region collected approximately 2 meters horizontally from the concretion. Contrasting plate-tectonic settings are indicated by the two differently cemented regions (fig. 5). The Middle Kittanning sandstone (Allegheny Group) samples show an even more pronounced dependence on cement composition. These samples (A and B, fig. 5) were taken approximately 0.05 meter apart horizontally. Sample A is bisected by a diagenetic front; detritus from the top (north) half is embedded in a carbonate-rich matrix, and that of the bottom (south) half is in a noncalcareous matrix. Sample B is largely identical to sample A except it lacks a well-defined diagenetic demarcation and a persistent calcareous matrix and contains globules of amorphous hematite grains and authigenic clay coatings. The coatings are absent at grain boundaries, indicating a diagenetic origin. Three hundred points were counted in sample B and 300 were counted on either side of the diagenetic front bisecting sample A to see which region, if any, was more representative of original detrital modes. As is the case with the Pottsville samples, the disparity between differently cemented regions/samples resulted in contrasting plate-tectonic interpretations. The "north" (calcareous) half of sample A plots near the boundary of the transitional continental region of the QmFLt diagram, and the "south" (noncalcareous) region plots within the quartzose recycled region. This difference is the result of a greater abundance of K-feldspar in carbonate-rich regions—an identical scenario to that of the calcareous and noncalcareous Pottsville Group samples.

## DISCUSSION

Uppermost Pottsville through middle Allegheny Group sandstones indicate that fluvial systems were transporting sediment derived primarily from the unroofing of plutonic sources of granitic-granodioritic composition. Davis and Ehrlich (1974) and Cox and others (1984) both found similar results in equivalent strata from the Pocahontas Basin of central and southern West Virginia. Sediment provenance here was interpreted to be located to the south and east of the respective study areas. However, Robinson and Prave (1995) and Chesnut (1994) found transport directions in equivalent strata in western Pennsylvania and eastern Ohio to be predominantly from the north in the Early Pennsylvanian. Beaumont and others (1987) predicted similar sediment-dispersal pathways for the Early Pennsylvanian as a result of a lack of thrusting in the central Appalachians. Presley and Donaldson (1984) alluded to this discrepancy in transport direction by expanding Meckel's (1967) notion of an early Pennsylvanian basin in eastern Ohio and western Pennsylvania. Termed the Northern Pottsville Basin (Presley and Donaldson, 1984), it was characterized as having an Appalachian source in northern West Virginia and a

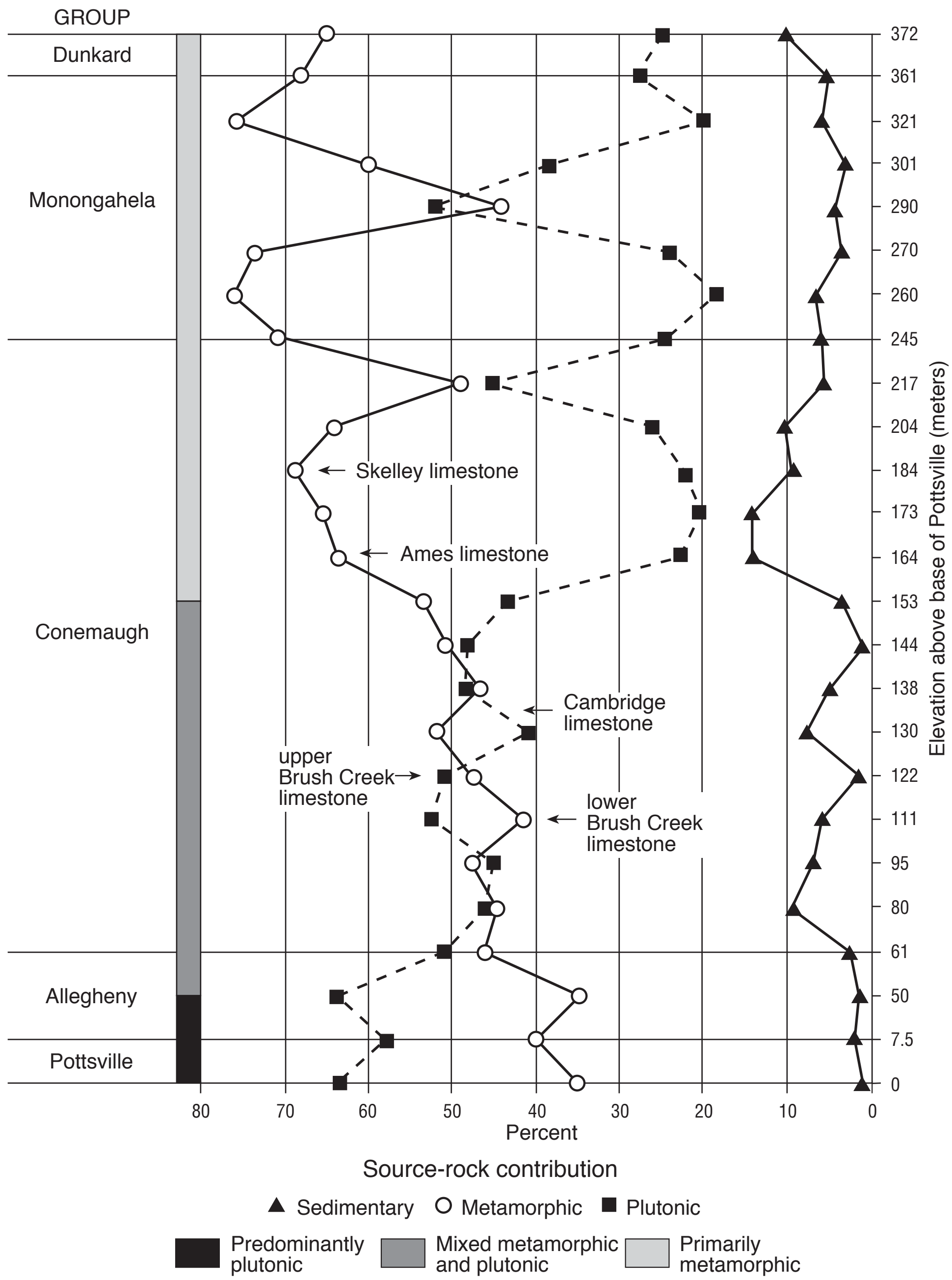



FIGURE 8.—Variation in provenance categories through the Pennsylvanian of Athens County. The stratigraphic positions of the Ames and Brush Creek limestones in the Conemaugh Group are shown for reference to figure 2.

possible cratonic source in northeastern and east-central Ohio—a distance of under approximately 100 km (Presley and Donaldson, 1984, fig. 2). However, there is general agreement in the literature (for example, Donaldson, 1974; Presley and Donaldson 1984; Beaumont and others, 1987; Chesnut 1991, 1994) that, by the Middle to Late Pennsylvanian, dispersal paths were to the north and west through the basin. The suggestion (Presley and Donaldson, 1984; Beaumont and others, 1987; Chesnut, 1991, 1994; Robinson and Prave, 1995) that southward-prograding paleodrainage persisted in eastern Ohio, western Pennsylvania, and northeastern Kentucky into latest Pottsville and Allegheny times could imply the persistence of an upwarped northern margin of the Appalachian Basin as suggested by Robinson and Prave (1995). This upwarped margin could possibly result in sandstone compositions similar to those found by Davis and Ehrlich (1974) and Cox and others (1984) in the Pocahontas Basin. However, it would necessitate the presence of a drainage divide between the Pocahontas and Northern Pottsville Basins during Pottsville and Allegheny time. Unfortunately, no statistically significant paleocurrent data exist in this portion of the basin to allow discernment of a northern or southern provenance.

Beginning with the Ames sandstone (164 meters, fig. 8), sandstone provenance shows a dramatic change throughout the remainder of the section. Post-Ames compositions show a substantial enrichment in metamorphic-derived detritus (figs. 8, 10). These enrichments are punctuated abruptly

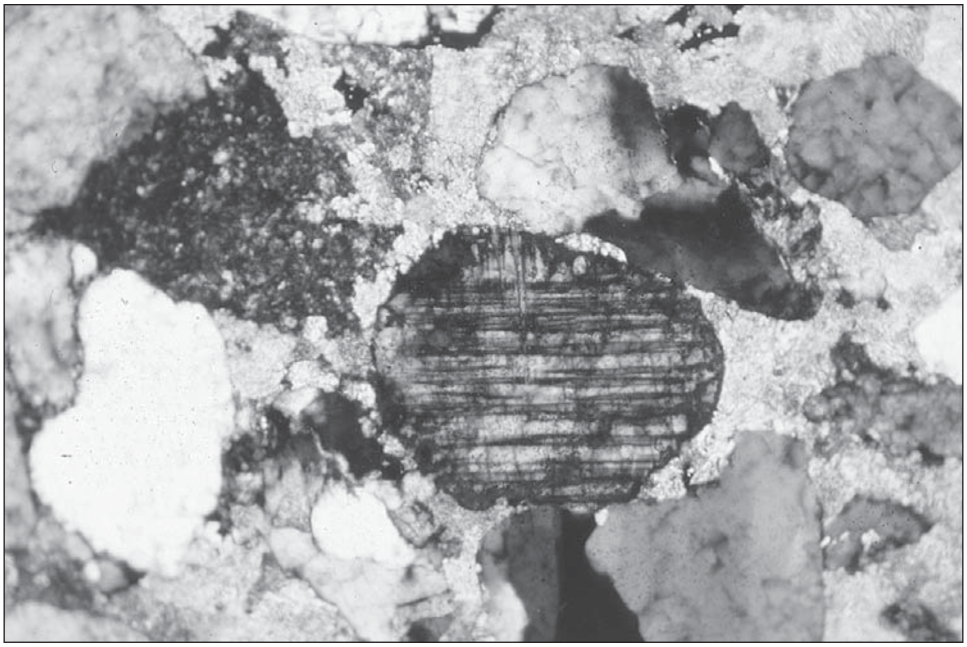


FIGURE 9.—Perthitic feldspar and monocrystalline quartz common in the Pottsville Group. Tionesta sandstone (Tionesta cyclothem). Field of view is 1.7 mm across.

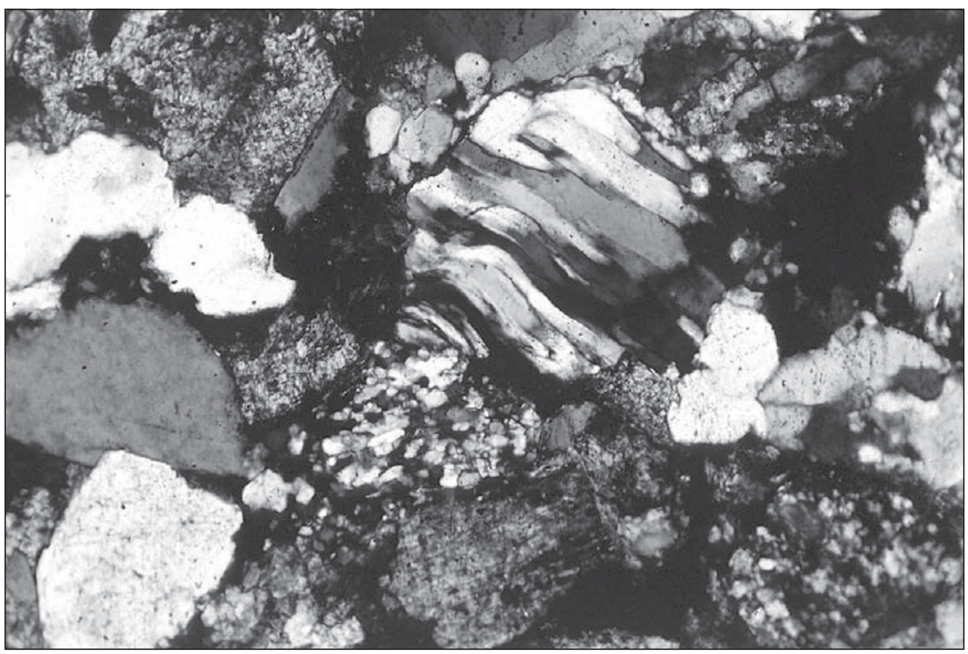


FIGURE 10.—Metamorphic-derived components in post-Ames sandstones. Upper Grafton sandstone (Elk Lick cyclothem). Field of view is 1.7 mm across.

by large, sudden plutonic contributions that are coupled with falling metamorphic abundances. The fluctuations are interpreted to represent the effects of episodic Alleghanian thrusting, punctuated by periods of erosion into a plutonic core. Alternatively, the plutonic contribution may at times be the result of the reintegration of uplifted sources to the north.

The different plate-tectonic interpretations derived from dissimilarly cemented regions of the same outcrop, or, in some cases, the same thin section, indicate that plate-tectonic interpretations derived from the use of ternary diagrams must be viewed with caution unless account is made for the effects of diagenetic alteration.

## IMPLICATIONS

The variations in Pennsylvanian sandstone provenance have interesting implications for the overall depositional style of the northern Appalachian Basin in the face of three generally accepted ideas. First, thrust-loading results in foreland basin creation and/or increased subsidence of pre-existing basins. Also, second-order, Late Carboniferous sea levels were at a maximum, relative to the Early and Middle Carboniferous (for example, Ross and Ross, 1987). Finally, Late Carboniferous paleoclimate was becoming increasingly arid, relative to the Early and Middle Carboniferous (for example, Schutter and Heckel, 1985;

Cecil, 1990; Parish, 1993; Heckel, 1995), at least within the midcontinent region. This information, when viewed in the context of the regional stratigraphy, highlights some of the incongruities associated with eustatic, tectonic, and paleoclimatic arguments regarding the generation of "Appalachian type" cyclothems. This disparity is particularly evident at and above the level of the Ames limestone. The Ames is the most areally extensive of all marine incursions into the Appalachian Basin and marks the position where the most pronounced change in provenance occurs. Marine limestones are absent above the Skelley limestone (184 meters, fig. 8). Yet provenance signatures indicate the proliferation of Alleghanian thrusting, thus implying maximum basin subsidence (Beaumont and others, 1987; Klein and Kupperman, 1992, fig. 3b) and an increased likelihood for marine incursions given the nature of Late Carboniferous sea levels. The lack of marine units in post-Ames sediments is interpreted to reflect progradation of a clastic wedge that was capable of overwhelming both maximum levels of basin subsidence and the eustatic signal.

## CONTROLS ON SEDIMENT DEPOSITION IN ATHENS COUNTY

The Pennsylvanian section in Athens County reveals variations in facies within cycles that are largely due to variations in eustatic and tectonic forcing within the basin. The interplay between tectonics and eustasy can be seen in the presence and absence of marine limestones within the section. In the Pottsville and Allegheny Groups, the magnitude and rates of eustatic sea-level fluctuations and tectonic subsidence were not sufficient to overcome the sediment influx and allow marine limestones to be deposited in the basin. The rarity of marine fossils in sediments of the Allegheny Group in Athens County and their occurrence in counties to the north and south suggests the influence of local structural uplift in the sediment distribution. The presence of marine limestones and shales in the Conemaugh Group shows that the eustatic/tectonic component was then great enough to allow inundation to advance far enough eastward to prevent the siliciclastic component from diluting the carbonate factory. This change also is reflected in a change in provenance that may indicate a change in sediment-dispersal patterns as well. The abrupt change in provenance above the Ames limestone points to a major basin reorganization. The timing of the event, at the long-term sea-level maximum, is consistent with the idea that tectonic subsidence augmented a short-term sea-level rise that overcame sediment influx to produce a major transgressive event (Heckel, 1994). Above the Skelley limestone, tectonic pulses were not of sufficient magnitude, or were out of phase with the eustatic variations, to offset the sediment influx to the basin and allow a significant marine incursion.

The interpretation of climate information preserved within the nonmarine limestones requires an understanding of the source rock as well as the fabrics and textures. Because of the presence of Early Paleozoic carbonates in the source area for the sediments of the northern Appalachian Basin as well as a location within the Late Carboniferous tropical rainy belt (Otto-Bleisner, 1993; DiMichele and others, 1996), an increasing ion concentration by evaporation is not essential for extensive carbonate accumulation in the Late Pennsylvanian.

Work is presently underway to analyze the sedimentologic and geochemical properties of the limestones in the Conemaugh Group vs. those in the Monongahela Group and interpret their paleoclimatic signals to see whether or not there really was a large-scale climatic change from arid to wet during the deposition of the Conemaugh limestones to the Monongahela limestones. Phillips and Peppers (1984) postulated such a climatic change based on the absence/presence of coals across these time slices in midcontinent cyclothems. However, no paleobotanical evidence presently exists for vastly different floras occurring between the supposed "drier" vs. "wet" times in Late Carboniferous sequences (DiMichele and others, 1996). In addition, paleolatitudinal data from Opdyke and DiVenere (1994) seem to show that the drift of the continent in the Pennsylvanian was toward the paleoequator, wholly within the wet tropical cells of the time (see fig. 2); there is no evidence for climatic change due to the transport of the region through a climate gradient. The key to solving this problem perhaps lies in the textures and fabrics of the nonmarine carbonates, which are archives of paleolimnologic signatures based on climatic change.

## ROAD LOG

| | |
|---|---|
| Mile 0 | Leave Ohio Union on The Ohio State University campus; take W. 12th Ave. east to High St. Turn right (south) on High St. Then left (east) on E. 11th Avenue. Proceed 1.1 miles to I-71, turn right (south) onto I-71. Merge left at I-71/I-70 split and follow I-70 east. |
| Mile 7 | Exit I-70 onto U.S. Rte. 33 south. |
| Mile 10 | Interchange of I-270 and U.S. Rte. 33. Continue south on U.S. Rte. 33. |
| Mile 28 | City of Lancaster. Continue on U.S. Rte. 33. |
| Mile 46 | STOP 1. Hocking County Road 25. Pull off onto CR 25 and park off the road. |
| Mile 73 | STOP 2. Peach Ridge summit. |
| | Continue on U.S. Rte. 33 east and exit onto U.S. Rtes 32/50 heading for Albany, approximately 0.5 mile past the exit for U.S. Rte. 33 to Pomeroy. |
| Mile 76 | STOP 3. Park off shoulder of U.S. Rtes. 32/50. |
| LUNCH | At Clippinger Labs, Ohio University. Return to U.S. Rtes. 32/50 and head north and east, taking the Parkersburg exit. Continue along U.S. Rte. 50. |
| Mile 88 | STOP 4. |
| | Retrace route to Columbus and OSU campus. |

## DESCRIPTIONS OF STOPS

### STOP 1

**Location:** U.S. Rte. 33 at Hocking County Rd. 25 (fig. 11)
**Unit:** Pottsville Group
**Age:** Desmoinesian?

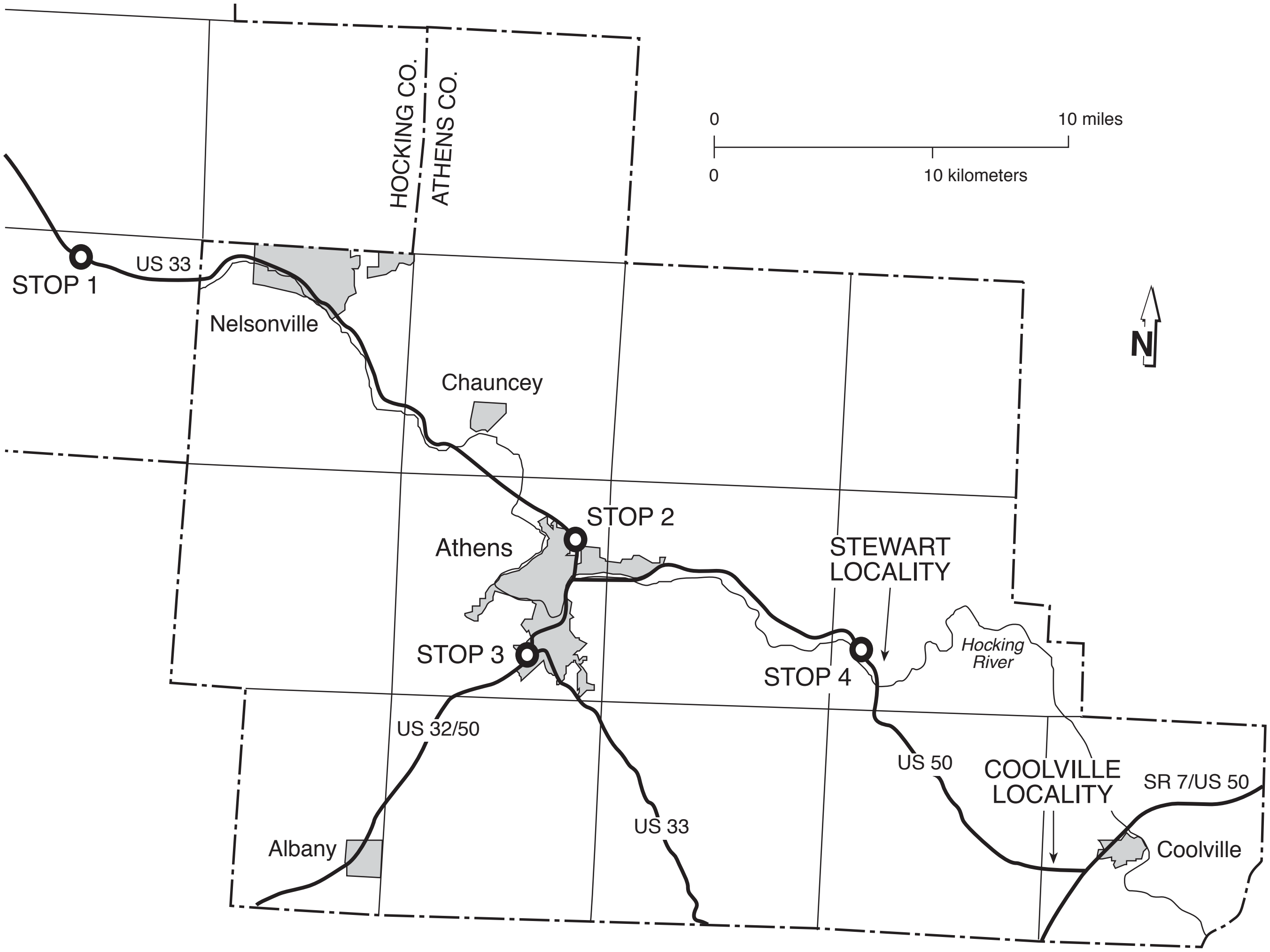



FIGURE 11.—Map of field-trip stops.

**Climate:** seasonal rainfall, savannalike
**Important points:** coal compaction, soil profiles, sequence boundary location

**Description:**

The strata exposed here are typical of the upper Pottsville Group. The base of the section is a series of brown to gray laminated mudstones to siltstones. These siltstones grade upward into massive brown to gray siltstones containing thin beds of very fine grained sandstone (fig. 12). The overlying light-brown mudstone shows no evidence of original depositional fabric, but breaks in an irregular blocky fracture. Slickensided surfaces are a common feature on the blocks. The dark-gray mudstone directly above, which is well laminated, is overlain by a thin coal that laterally abuts against the overlying sandstone. The sandstone contains a basal lag of plant and coaly debris, is medium to coarse grained, and trough cross bedded. Paleoflow was to the northwest.

**Interpretation:**

The lack of laminations and the presence of slickensides on block surfaces in the brown mudstone and underlying siltstones indicate the development of a soil profile (that is, subaerial exposure) on what are either marine or lacustrine deposits. The soil was then covered by water that deposited the organic mudstones (possibly lacustrine) and then the coal. The lateral discontinuity in the coal means that conventional decompaction ratios (typically 10:1) produce unacceptable distortion in the overlying sandstone. The geometry of the deposit means that (1) compaction of the organic material occurred after burial of only a few meters, and (2) coal decompaction ratios on the order of 1.2:1 to 1.4:1 are more realistic. (See Nadon, 1998, for more information on this topic.)

The conventional cyclothem boundary would be placed at the base of the sandstone body (fig. 4), but the sequence boundary occurs either between the brown mudstone and the dark-gray mudstone or between the brown mudstone and the siltstone/very fine grained sandstone underneath. The former position assumes no aggradation of the floodplain during the lowstand; the latter position would place the brown mudstone into the lowstand systems tract (LST).

STOP 2

**Location:** U.S. Rte. 33 cut through Peach Ridge (fig. 11)
**Unit:** Conemaugh Group
**Age:** Virgilian
**Important points:** incised valley fill

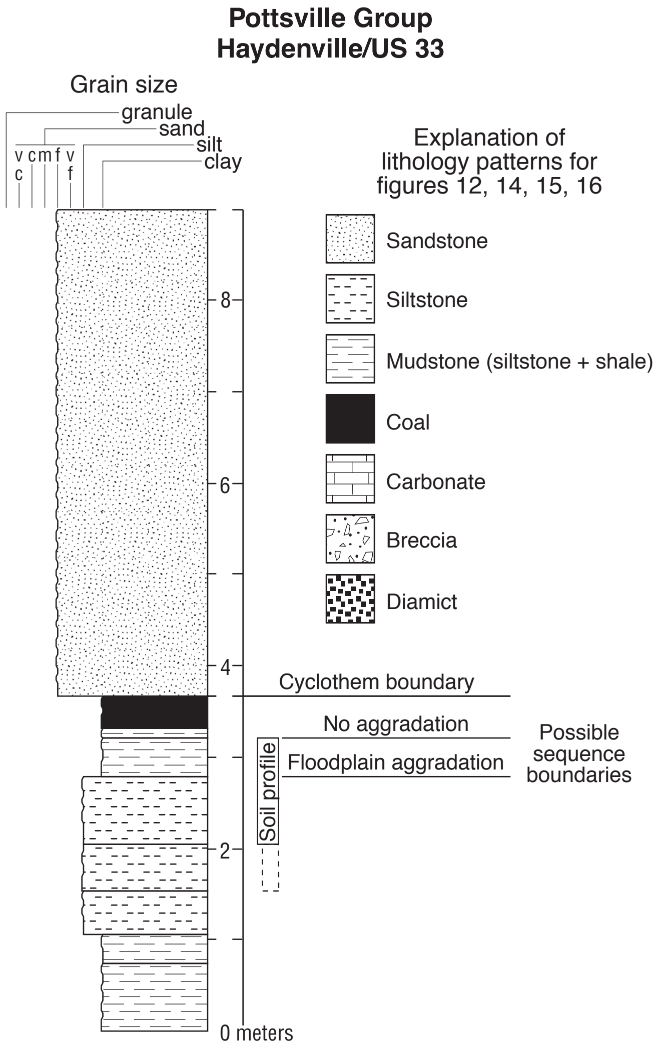



FIGURE 12.—Measured section for Stop 1 in the basal Pottsville Group along U.S. Rte. 33 near Haydenville, in eastern Hocking County. Sand grain-size abbreviations are: vc, very coarse; c, coarse; m, medium; f, fine; vf, very fine.

**Description:**

The Connellsville sandstone is well exposed along the road at Peach Ridge (see cover photo). Note that on the drive up the west side of the hill the massive sandstone is very close to the crest of the hill. As we continue to the next stop, notice that this sandstone continues down the east side of the hill for some distance. This multistory sandstone body is 26 meters thick at this location and has a maximum thickness of 32 meters, more than three times the thickness of an average cyclothem sandstone. Grain size at Peach Ridge ranges from upper medium grained to very coarse grained and there are scattered quartz pebbles. Internal structures of the sandstone include trough cross beds, rare ripples, and lateral accretion surfaces.

**Interpretation:**

The presence of the lateral accretion surfaces, although not absolutely diagnostic, indicate that the Connellsville sandstone at this location was deposited by a meandering fluvial system. The cross-cutting relationships between the individual sandstone bodies are indicative of a low rate of formation of accommodation space. This geometry is especially evident along the north wall at the top of the hill. An isopach map of the locations that only contain coarse-grained sandstones (fig. 13) shows the linear nature of the sandstone lithosome, which is interpreted to represent an incised valley deposit. Similar valley deposits have been described elsewhere within the Carboniferous (Aitken and Flint, 1994).

The incised-valley interpretation has at least two important consequences. First, the correlations of Sturgeon and associates (1958) would be inaccurate at this stratigraphic elevation because deposition of one to three cyclothems may have occurred only within the valley after it was cut. The sandstones within the valley would all be younger than the strata at the same stratigraphic position on the south side of the Hocking River. Second, there must have been a major drop in relative sea level. If this drop is not recognized elsewhere there is the possibility that we are seeing the effects of local tectonic uplift rather than a basinwide sea-level change.

**Key references:** Aitken and Flint (1994).

STOP 3

**Location:** road cut at intersection of U.S. Rtes. 33 and 50/32 (fig. 11)
**Unit:** Conemaugh Group
**Age:** Virgilian
**Important points:** a complete cyclothem, major petrographic change

**Description:**

This exposure allows easy access to the entire Ames cyclothem/sequence/alloformation (fig. 14). The base of the exposure is a massive gray mudstone that breaks into small blocks at road level at the southern end of the outcrop. (Note the slump above this section, which happened on January 11-13, 1998). This mudstone is capped by well-laminated dark-gray marine mudstone that grades into medium-gray mudstone. The latter are truncated by a sandstone, which contains scattered brachiopod shells. The sandstone is massive to low-angle laminated at the base and thinly bedded at the top. Low-angle truncation surfaces are common. The sandstone is overlain by a thin, laminated mudstone and then by the Ames limestone, the most persistent limestone in Athens County. The allochems in the Ames at this location consist mainly of crinoid fragments; brachiopod shells are common and corals are rare. Above the Ames are more laminated mudstones that grade into massive, variegated red to purple mudstones. The upper mudstones have no trace of original laminations and break into blocks of various sizes that have slickensides on the surfaces. The top of the massive mudstones is marked by a sharp contact with overlying well-laminated dark-gray mudstones.

**Interpretation:**

The massive mudstones at the base and top of the section represent paleosol profiles. The gray color of the basal paleosol (top of the sub-Ames paleosol of Joeckel, 1995) indicates it was gleyed; the more red/purple colors of the upper mudstones indicate an oxygenated depositional setting (fluctuating water table?). The thick sandstone near the base of the section probably represents a distributary

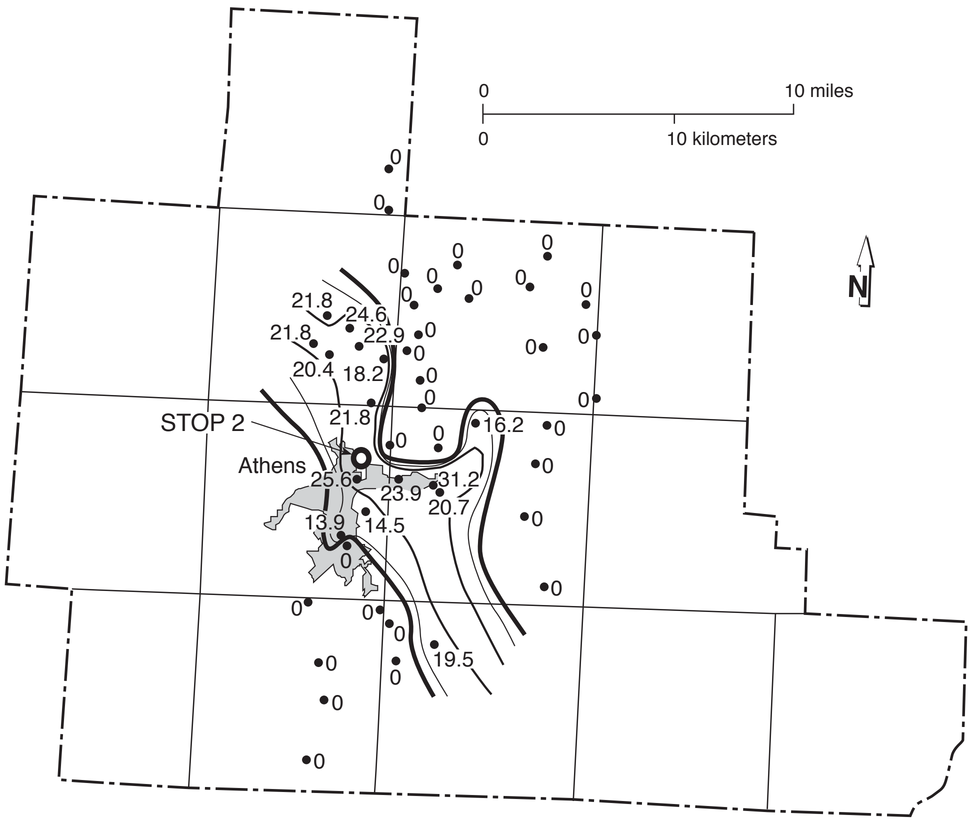



FIGURE 13.—Isopach map of the coarse-grained Connellsville sandstone. The location of Stop 2 within this incised-valley deposit is indicated. Data compiled from Sturgeon and associates (1958).

mouth bar reworked by storm waves, inferred from the low-angle truncation surfaces interpreted as hummocky cross-stratification. This sandstone conventionally forms the base of the Ames cyclothem; however, this sandstone ends rather abruptly approximately 20 meters north of the measured section. By contrast, the sequence boundaries represented by the tops of the soil profiles and capped by transgressions, which represent the contacts of the Ames alloformation, are traceable to adjacent sections even in the absence of the sandstone unit (fig. 15).

**Key references:** Joeckel (1995).

STOP 4

**Location:** new section of road along U.S. Rte. 50 west of Guysville (fig. 11)
**Units:** Conemaugh/Monongahela Groups
**Age:** Virgilian
**Climate:** tropical
**Important points:** abundant nonmarine (or brackish) limestones

**Description:**

This new road cut exposes 70+ meters of a sequence spanning the uppermost Conemaugh Group through a large portion of the Monongahela Group (fig. 16). In the older terminology, this interval separated the Lower Barren Measures from the Upper Productive Measures. The base of the section exposes a series of variegated green, gray, and bright-red mudstones of the Upper Pittsburgh redbed of the Pittsburgh cyclothem (Sturgeon and associates, 1958). The mudstone to limy mudstone comprises a series of beds displaying a wide variety of textures, including large, low-angle fractures, brecciation, and small blocks that have slickensided surfaces. Some of the beds can be better categorized as lime breccia mudstones to lime diamictites (fig. 17). The mudstone is capped by the Upper Pittsburgh limestone (meter 6-10), which consists of a series of discontinuous beds of nodular to massive limestone averaging 2.5 meters in thickness. Above this limestone is a thin coal seam, identified as the Pittsburgh coal by Sturgeon and associates (1958), overlain by laminated dark-gray shale. The Pittsburgh coal marks the base of the Monongahela Group. With the exception of the series of interbedded carbonate and shale/mudstone representing the Fishpot limestone (meter 19-22), approximately 12 meters above the Pittsburgh coal, the remainder of the section consists mainly of thin beds of sandstone interbedded with fine siliciclastics that range from light-gray to green and well-laminated shales to red/purple mudstones having blocky to massive textures.

The carbonates do not contain any diagnostic marine fossils. Fossils found to date include fish teeth and scales, carbonized macrophytic remains, probable microbial lamination (fig. 18), and ostracode shells (fig. 19). The carbonates are mostly calcitic, although one layer in the Fishpot limestone is dolomitized (approx. meter 20), and they can contain up to 50 percent siliciclastic material. Many are also petroliferous, perhaps serving as source rocks for the natural gas plays in southeastern Ohio. The Pittsburgh and the Fishpot generally consist of alternating limestone layers, averaging decimeters in thickness, and fine siliciclastic layers, millimeters to decimeters in thickness. Rock types in the carbonate units include clastic grainstone (fig. 20), intramicrite, laminated to thin-bedded micritic limestone, and lime breccia mudstone that includes features such as

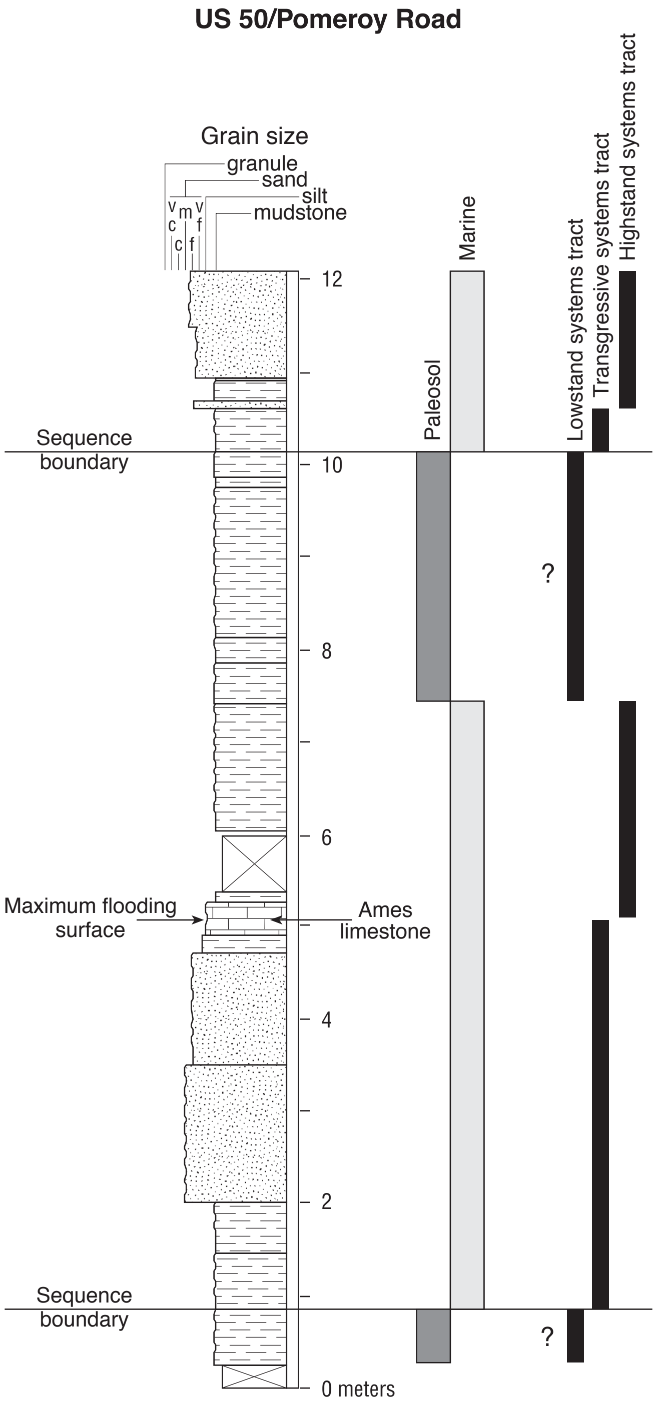



FIGURE 14.—Measured section for Stop 3 through the Ames cyclothem/alloformation south of Athens at intersection of U.S. Rte. 50 and Pomeroy Rd. The sandstone that forms the base of the cyclothem is discontinuous. The maximum flooding surface (MFS) is within the Ames limestone. The soil profile at the base is described from different locations in Joeckel (1995). See figure 12 for explanation of lithology patterns and sand grain-size abbreviations.

in situ brecciation (fig. 21), root structures with and without carbonized material (fig. 22), and sparmicritization.

Most of the major sandstone bodies in the section are exposed farther east along the highway. All are highly lenticular. Note that the margin of the western channel that is exposed in the main outcrop feathers into the floodplain sediments.

**Interpretation:**

The remarkable aspect of this section is the abundance of nonmarine (or brackish) carbonates associated with mostly siliciclastic fines. These rocks are interpreted as distal floodplain deposits. In larger basins that have mixed carbonate/siliciclastic source areas, carbonate accumulation occurs mostly in distal areas where suspended to dissolved load can be effectively separated from bedload deposition. This separation can occur in wetland areas/floodplains protected by levees (Aqrawi and Evans, 1994; Valero Garcés and others, 1994; Weedman, 1994) associated with anastomosing rivers. The carbonate units in this Guysville sequence are interpreted as such carbonate lakes/marshes. The variety of fabrics in the carbonates may indicate complex facies changes within marshes and small lakes—from clastic transport of carbonate grains to formation of microbial mats to quiet-water accumulation of micrites to early diagenetic alteration. Further research is underway to plot facies changes and study the detailed petrology of these limestones.

The multicolored mudstones at this locality are interpreted as paleosols. Evidence includes large low-angle fractures, blocky textures, and slickensides. Detailed work is needed to identify possible soil types and classify the complexes of multiple paleosol horizons. The brecciation and limited transport of very angular to subrounded clasts of mudstone to limestone are interpreted as mud-dominated flows. The origin of these flows is unknown.

The lenticular sandstone bodies are composed of both channel and levee sediments. The lack of sharp lateral margins and the contact of the levee sediments with well-laminated (lacustrine) floodplain deposits are indicative of rapid aggradation and anastomosed fluvial deposits (Nadon, 1994).

The assignment of cyclothem or sequence-stratigraphic boundaries in the Monongahela Group is not easy. The rapid lateral variation in facies, the lack of diagnostic fauna or flora, and the abundance of paleosols make correlation difficult. There appears to be little point in trying to apply the cyclothem paradigm to a section that has few of the criteria needed to recognize a cyclothem. Provisional sequence boundaries have been identified within the section (fig. 16) largely on the basis of a contact between a paleosol horizon below and shales above.

**Key references:** Sturgeon and associates (1958), Aqrawi and Evans (1994), Nadon (1994), Valero Garcés and others (1994), Weedman (1994).

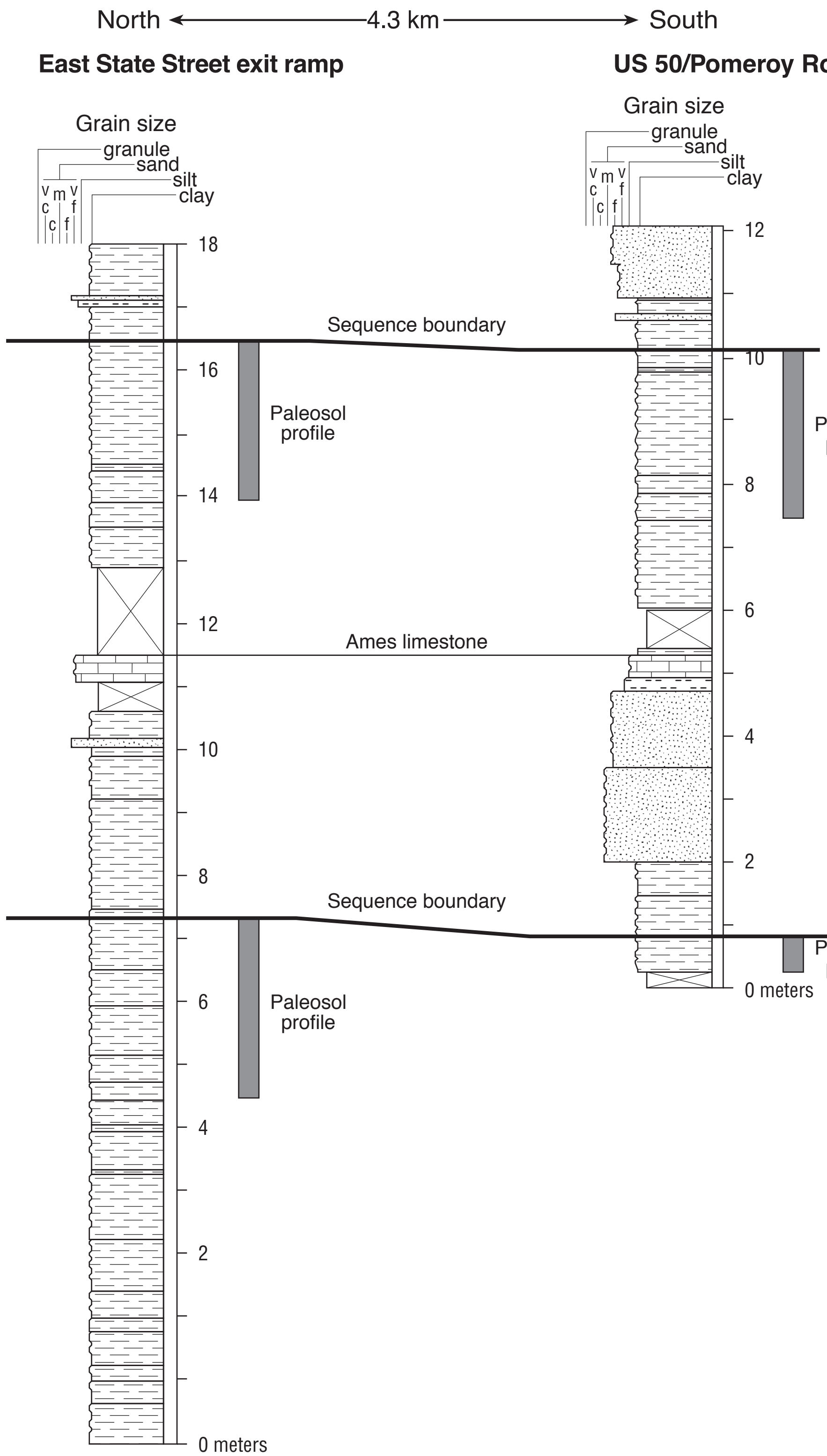



FIGURE 15.—Correlation of the Ames alloformation north of Stop 3 based on paleosols and the marine limestone. See figure 12 for explanation of lithology patterns and sand grain-size abbreviations.

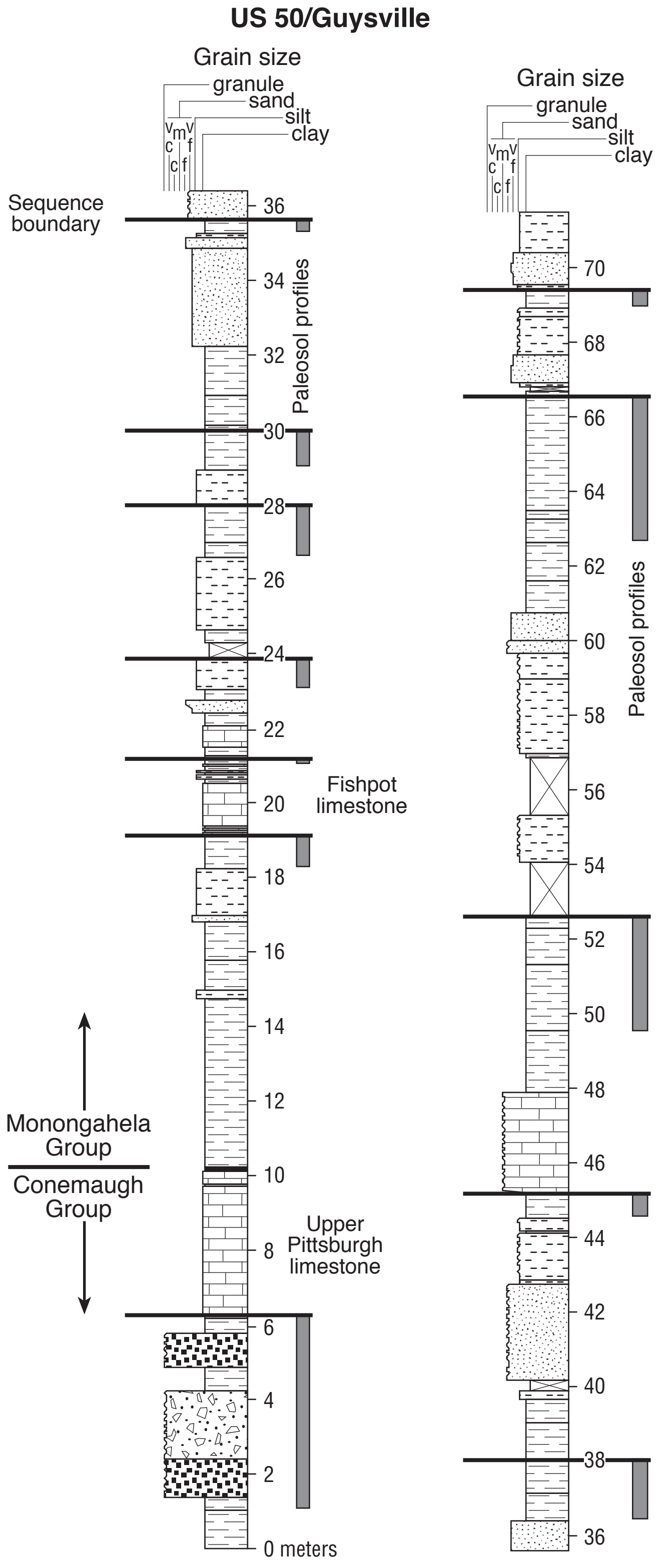



FIGURE 16.—Measured section for Stop 4 through the upper Conemaugh Group and most of the Monongahela Group along U.S. Rte. 50 west of Guysville. The tops of sequences in the provisional subdivision of the section are placed at the upper boundaries of major paleosol units. See figure 12 for explanation of lithology patterns and sand grain-size abbreviations.

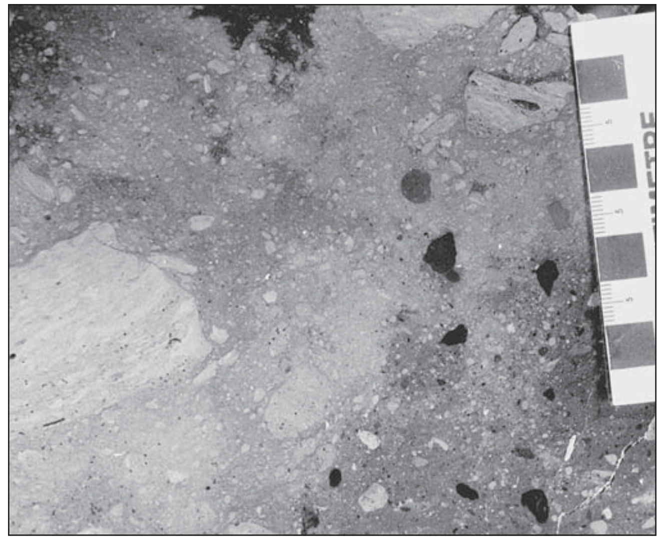


FIGURE 17.—Rock slab of lime breccia mudstone. Coolville section (see fig. 13) on U.S. Rte. 50, Upper Pennsylvanian-Permian. Scale in centimeters. Photo by K. D. Kallini.

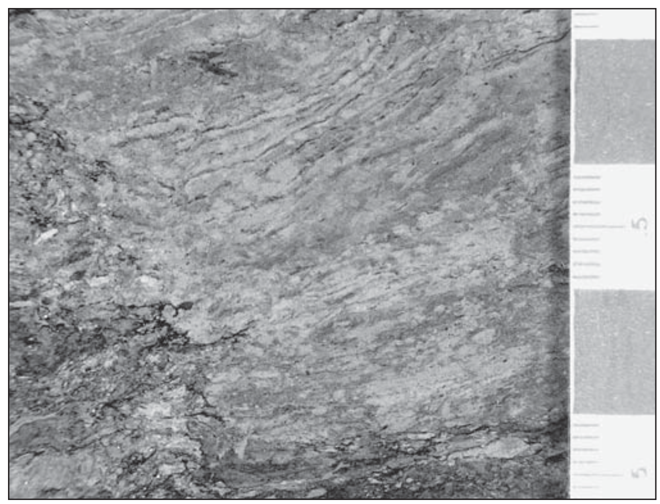


FIGURE 18.—Rock slab of dark carbonate containing possible microbial lamination. Guysville section on U.S. Rte. 50, Upper Pittsburgh limestone, Conemaugh Group (Virgilian). Scale in centimeters. Photo by K. D. Kallini.

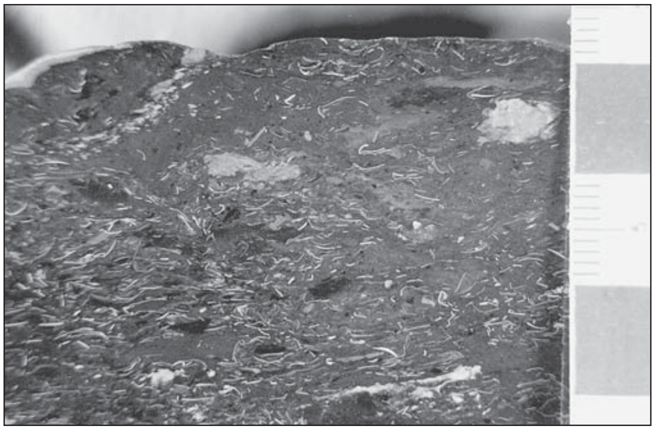


FIGURE 19.—Rock slab of clayey micrite containing ostracode shells. Guysville section on U.S. Rte. 50, Upper Pittsburgh limestone, Conemaugh Group (Virgilian). Scale in centimeters. Photo by K. D. Kallini.

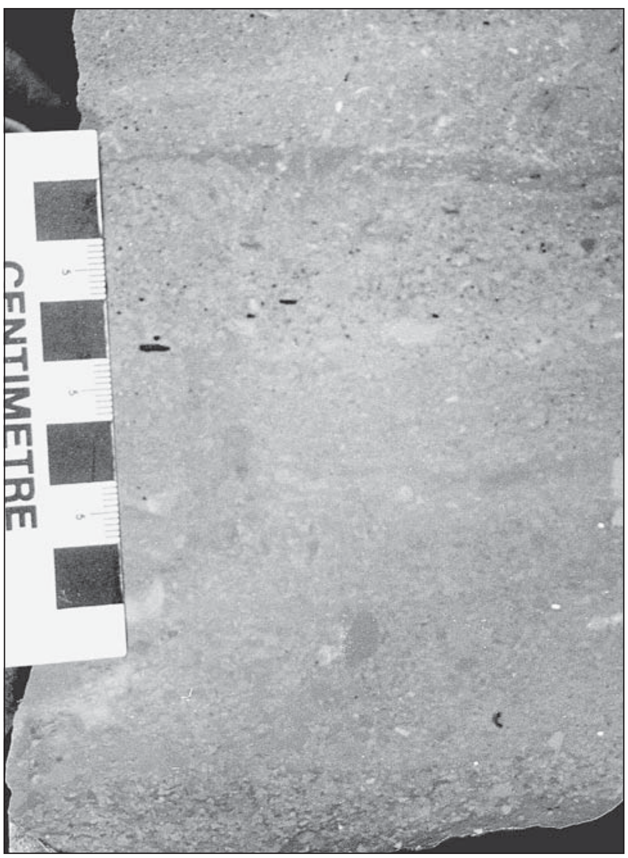



FIGURE 20.—Rock slab of lime grainstone (a clastic carbonate). Stewart section (see fig. 13) on U.S. Rte. 50, Fishpot limestone, Monongahela Group (Virgilian). Scale in centimeters. Photo by K. D. Kallini.

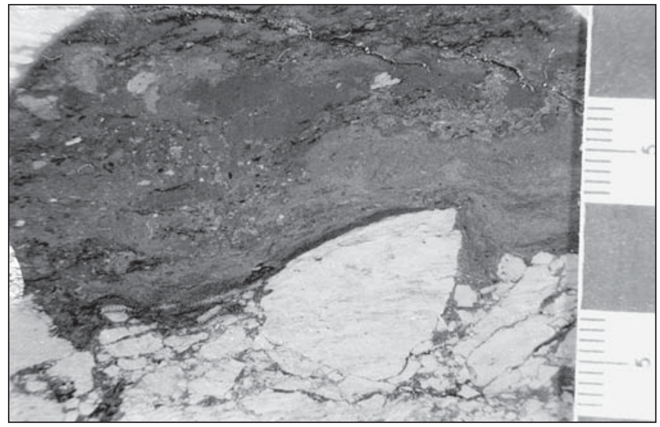


FIGURE 21.—Rock slab of micrite exhibiting in situ brecciation of lower micrite and a darker, more clay rich micrite above. Possible early diagenetic alteration within both micritic layers is indicated by pseudoclastic textures. Guysville section on U.S. Rte. 50, Upper Pittsburgh limestone, Conemaugh Group (Virgilian). Scale in centimeters. Photo by K. D. Kallini.

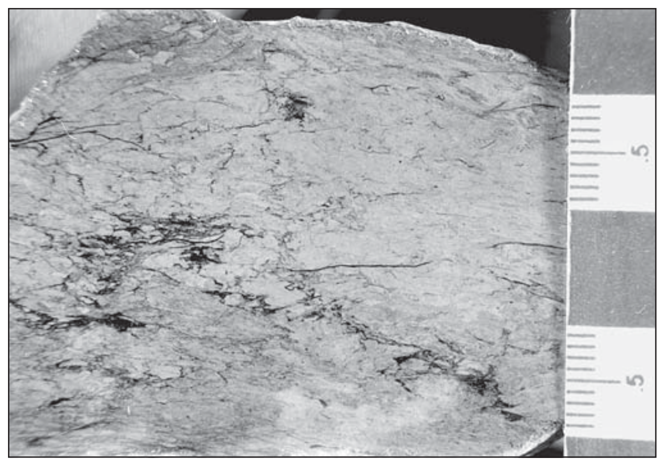


FIGURE 22.—Rock slab of micrite containing abundant coalified macrophytic remains, some within root structures. Stewart section (see fig. 13) on U.S. Rte. 50, Fishpot limestone, Monongahela Group (Virgilian). Scale in centimeters. Photo by K. D. Kallini.

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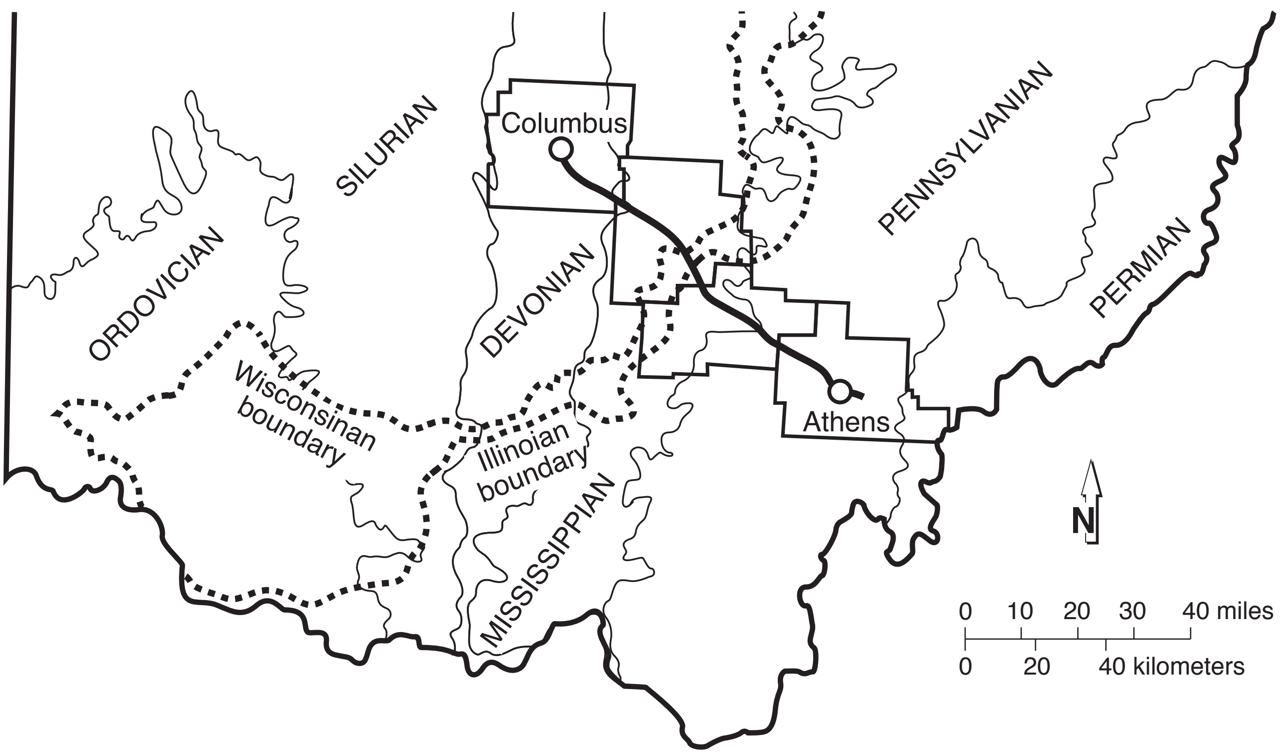


GENERALIZED MAP OF FIELD-TRIP ROUTE